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Design of Ventilation System for Commercial Kitchen

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Abstract - *The design for ventilation system of a commercial kitchen varies depending on the available space and the amount of food being prepared. The commercial kitchen is hot and humid, the occupants spend a lot of time there. Mechanical extract ventilation system and Single Island canopy are designed in this paper for a big commercial kitchen that produces fried goods in a continuous fryer with dimensions of 3.85m × 0.56m. The mechanical extract ventilation system lowers the temperature in the kitchen in this case study. When it comes to ventilation design, the exhaust flow rate is crucial. The exhaust flow rate is estimated using the SMACNA technique and appliance duty category, taking into account all room constraints and data from the case study. A single island canopy was created for the commercial kitchen ventilation (CKV) system. The amount of heat gained is not taken into account. Grease is a significant pollutant that is contained in a baffle filter in the kitchen without splitting. Filters placed in a 'V' shape under a single island canopy. To transport exhaust from the frying zone to the atmosphere, a ducting system is constructed, a blower is chosen, and it is mounted above the canopy. CFD simulations at various flow rates estimated from heavy duty and medium duty are carried out. Simulations demonstrate that adding a single island canopy with ventilation system reduces the temperature of kitchen by 8.19°C, preventing an increase in kitchen temperature. Safe, healthy, and agreeable working conditions were established.*

Key Words: **Commercial Kitchen Ventilation (CKV), Single Island Canopy, Mechanical Extract Ventilation, Baffle Filter, Exhaust Flow Rate**

1. INTRODUCTION

In recent years peoples are more conscious about indoor environment in commercial kitchen. High temperature and cooking particulates are unavoidable and intent to damage occupant health. Particulate matter create risk of respiratory infection, heart diseases, etc. In order to make comfortable working environment for occupant who spends considerable time there, heated air and moisture need to be exhausted. To control indoor environment mechanical exhaust ventilation system plays important role. To create safe, healthy, acceptable working conditions pollutants produced from kitchen area need ejectment. In order to make effective ventilation system canopy is intended to incorporate all contaminants above cooking surface i.e. fryer. Mechanical exhaust ventilation system should be prudential of all smoke, odour, heat that is produced during frying process and promote comfortable indoor working conditions. Canopy or hood is the device intended to collect all ejected pollutants from kitchen and hold the pollutants until it gets evacuated by adjacent blower. Kitchen pollutants should be exhausted by using arrangement of canopy, where blower, filter and duct are used as mountings. The canopy must be capable to collect all the pollutants effectively. Grease is the combination of water vapor and oil that produced from fried products.

Fried goods are produced in the commercial kitchen. This generates grease (combination of oil and water), pollutants which disperses around the kitchen, and the heat generated raises the temperature. Liu et.al [1] found that the temperature condition in the kitchen was very non-uniform and excessively hot. During cooking, the ambient temperature in the kitchen may rise by 5.3 ^{0}C. Han et.al [2] stated that as variables affecting hood performance, disturbing airflows, hood geometric features and placements, and exhaust airflow rate are all investigated. A wall-mounted canopy need a lower exhaust airflow rate than a single-island canopy. Kosonen et.al [3] the airflow rate required to remove the contaminants was studied by the researchers. Undersized airflow rates may cause indoor air quality issues, while an excessive ventilation system consumes unneeded energy.

Zhang et.al [4] identified the construction of the kitchen indicates the position of the exhaust hood. Chen et.al [5] studied that to enhance the thermal environment, a CFD model can precisely represent variations in fume concentration in the kitchen. The distribution of fume concentrations as the exhaust air volume is changed. Jiao et.al [6] used CFD as tool to find different locations in room that cause easy ventilation. Ji et.al [7] noted that when dust loads increase, the filters' long-term performance may alter, and the filters may become particle sources themselves, affecting the operation of other systems. As a result, this filter must be cleaned and washed on a frequent basis to avoid this. Sha and Qi [8] seeks to save money by using the mechanical ventilation system for ventilation. Kumari et.al [9] stated the key to achieving optimum ventilation is proper ventilation system size. Exhaust quantity is identified first for better results. Pollard [10] Gives information about first step in designing a kitchen exhaust system is to calculate the amount of emissions. In addition, vital kitchen ventilation equipment are described. Duct outlet must be at least 1m above the roof surface area. Indian Standard IS 3646 [11] identified in the kitchen, lighting is a crucial factor. As people working in the kitchen want adequate illumination for successful operation. This Indian standard provides information on the degree of light in various environments. Under canopy, a total of 500 lux is necessary for the kitchen exhaust system. CPWD [12] [30] information about extract ventilation is given as well as duct fabrication details such as 22.5^0 is used for contraction and expansion is given.

ASHRAE standard [13], [14], [15] standard specifies per linear foot of hood length, maximum net ventilation flow rate in cfm. The ASHRAE has its own technique for calculating the exhaust flow rate. Exhaust hood types, baffle and mesh filter are explained. Baffle filters are primary filter and secondary mesh filter are not used for frying process. CIBSE Guide B2 [16] [17] this standard explains the duct design process. The constant pressure loss rate for the equal friction technique is stated as 0.8–1.2 Pa.m−1. The equal friction loss approach is simpler to build with and results in reduced duct diameters. Ducts that are sized using this approach can cost up to 8% less than those that are sized using the static regain method. Wong [18] selection and utilization of grease trap filter. Industrial Ventilation [19] given procedure to find cooking duty and SMACNA method for calculation of exhaust explained. ISHRAE [20] Different velocities for different applications are given. 1800 fpm is the velocity recommended for exhaust duct. ASHRAE Pocket Guide [21] recommended stainless steel with a minimum thickness of 18 gauge is required for the construction of the duct and canopy. Because the duct and canopy must handle an oil and water mixture, i.e. grease, the materials used must be corrosion resistant. Asmuin et.al [22] [23] Because the simulation findings are more accurate, the K-epsilon (k-ϵ) model was chosen over the other models for simulation analysis.. Livchak [24] The efficiency of the filter depending on the manufacturer. NFPA 96[25] material for canopy construction is explained. Bhatia [26] recommended outside of the hood/canopy must be made of at least 18 gauge (1.27 mm) galvanized steel or stainless steel. Li [27] indoor air condition are identified with CFD simulation. For that different air flow rates are taken into consideration. Koch [28] Experiments were conducted to see if hydraulic diameter could be used as a "equivalent diameter" or if another connection could be found. The equivalent diameter of the rectangular duct is 4.5 % smaller than the hydraulic mean diameter. ANSI/ASHRAE [29] The minimum velocity for hood exhaust ductwork is 500 feet per minute (2.54 meters per second). Bell [31] For duct outlets, a neck and radius bend are required with a radius equal to 1.5 times the width of the duct (r/w = 1.5).

2. RESEARCH METHODOLOGY

2.1 Case Study

There are various subtypes of ventilation system as natural, mechanical etc. out of mechanical extract ventilation system used in contaminated areas. [12] Figure shows setup of commercial kitchen for which ventilation system is designed.

Fig-1: Fryer Setup

Type of cooking duty, power source, size of fryer, kitchen size, grease, heat, smoke, layout of room, space for canopy, room restrictions etc. are the prerequisite that considered for designing ventilation system. Average illumination levels at the work surface of 500 lux. [10] [11] Cooking appliances are classed as light-, medium-, heavy-, and extra-heavy-duty based on the strength of the thermal plume and the amount of grease, smoke, heat, water vapour, and combustion products produced. [14] Here continuous fryer falls in medium to heavy duty category. Fryer having dimensions of 3850 mm × 560 mm.

2.2. Canopy/ Hood and Exhaust flow rate

Hoods are placed at various heights and horizontal locations in relation to the cooking equipment and have varied capture areas. Here Single island canopy is suitable as shown in Fig - 2. The outside of the hood must be made of at least 18 gauge (1.27 mm) galvanized steel or stainless steel. [26]

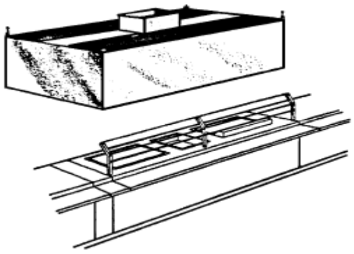

Fig- 2 Single Island Canopy [15]

Here canopy dimensions are calculated by SMACNA method:

$W_h = W_s + 0.8H = 3850 + (0.8 \times 1000) = 4650$ mm

$L_h = L_s + 0.8H = 560 + (0.8 \times 1000) = 1360$ mm (H = 1000 mm) [19]

Exhaust flow rate for medium duty category is 5914 cfm (2.79 m^3/s)

Exhaust flow rate for heavy duty category is 7886 cfm (3.72 m^3/s)

2.3 Filter

The primary function of the filter is to prevent contaminants from entering the canopy. Filters are classified into two types: primary filters and secondary filters. Primary filters do not require any extra filters and are capable of preventing flames from entering the canopy and causing blower damage. Secondary filters are those that are used in conjunction with main filters. Mesh filters are secondary filters that are unsuitable for this case study since they do not store oil and provide no protection to the blower as baffle filters do.

Filters must be installed at the hood's discharge opening since any grease that drains from the filters is collected and disposed of without spilling or polluting the kitchen area. Baffle filters must be placed at a 45^0 angle from the horizontal. [10] From catalogue baffle filter is selected having parameters as 18×18×2 inch at velocity of 1.5 m/s, flow rate of 0.31 m^3/s with constant pressure drop of 125 Pa.

2.4 Canopy Lighting

500 lux of illumination is required for kitchen area. [10] The average lighting in the kitchen area, as measured by a lux meter, is 658 lux. As a result, the amount of illumination is sufficient, and no additional lighting is required.

2.5 Ductwork

The equal friction approach sizes the air duct so that duct friction loss per unit length is consistent throughout all duct sections. Low-pressure systems typically use 0.82 Pa/m (0.1 in. WC per 100 ft) which is based on experience. [17] Blower of suitable exhaust CFB4D-225D is fitted inside canopy.

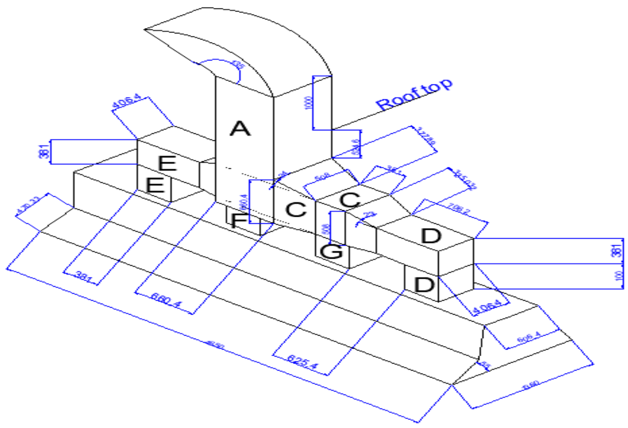

Fig -2: Duct above Canopy

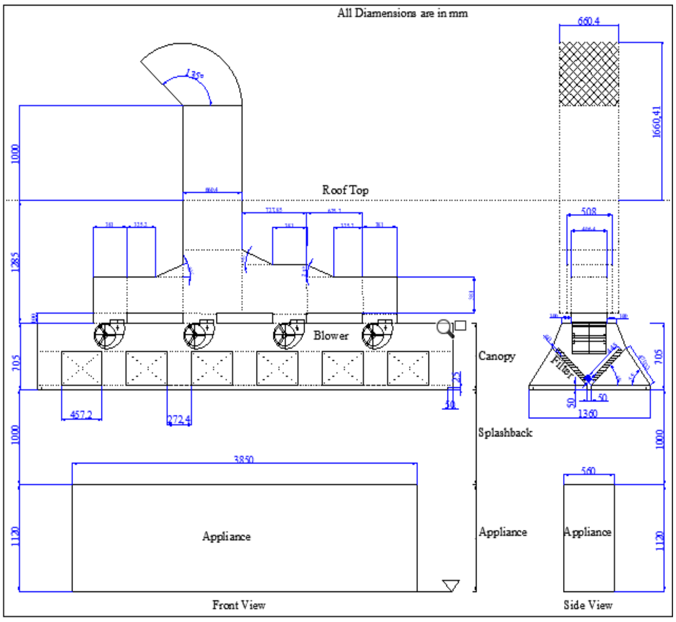

Fig -3: Designed setup of Commercial Kitchen Ventilation System

3. RESULT

As a result, the ambient air temperature inside the kitchen may rise to 5.30°C during cooking. [1] As a result, the initial measured temperature of the commercial kitchen was 27°C. When the fryer was turned on, the kitchen's dry bulb temperature reached 35°C, with a wet bulb temperature of 25°C. As a result of the high temperature, water vapor and oil from the fryer evaporated and mingled in the air, relative humidity in the occupant zone reached 44.1 %. To lower the temperature in the kitchen, the air must be evacuated. As a result, the outlet boundary condition for CFD simulation is the exhaust flow rate computed from the medium and heavy load categories.

3.1 CFD Simulations

In this study the heat source is continuous deep fat fryer having temperature of 468 K working as heat source and having dimensions of 3.85m × 0.56m. Surrounding working zone of fryer is highly affected, that raises temperature and causes unhealthy environment. Ansys Fluent 2020 R1 was used to complete all CFD simulations. The equations for mass, momentum, and energy conservation were solved using the finite-volume method. For turbulence closure, the conventional k-ϵ model was used, and the ideal gas law was used to describe buoyancy. All simulations were run in steady-state mode. The governing equations were discriminated using first order discrimination.

Table -1: Commonly used boundary conditions for kitchen ventilation system

	without ventilation system	with ventilation system Medium Duty	With ventilation system Heavy Duty
Model	k- ϵ	k- ϵ	k- ϵ
Initial Kitchen temperature (K)	300	300	300
Temperature of Fryer (K)	468	468	468
Walls of kitchen (W/m²)	0 =Adiabatic heat flux	0 =Adiabatic heat flux	0 =Adiabatic heat flux
Outlet	Pressure Outlet	-	-
Mass Flow Outlet (kg/s)	-	3.49	4.65

3.2 Without Ventilation System

To verify the calculated exhaust flow rates, first determine the temperature of the kitchen without the use of a ventilation system. For this simulation outlet condition is pressure outlet. The boundary conditions of without controlled ventilation are used to run CFD simulations:

Without a ventilation system, the temperature in the kitchen rose to 311.54 K from 300K seen in Fig -5 (a). Fig -5 (b) shows temperature of fryer decreased up to 463.52K

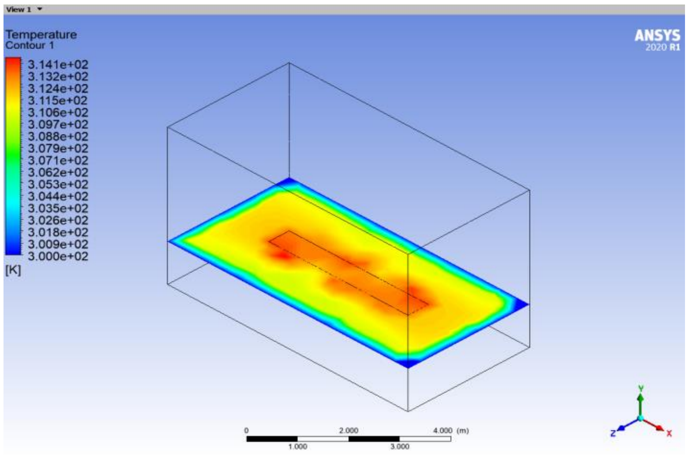

Fig -5 (a): Temperature contour of kitchen without ventilation system

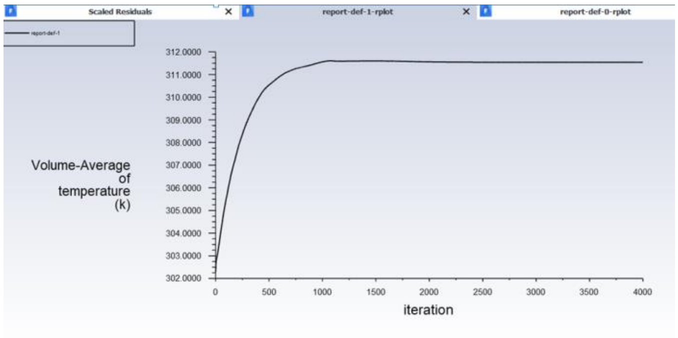

Fig.5 (b): Volume average temperature rise of Kitchen

3.3 With Ventilation System- Medium Duty

The flow rate computed from the medium duty category is utilized as the mass flow outlet condition to test the effect of varied flow rates on temperature. Exhaust flow rate is calculated in cfm, however mass flow outlet condition is translated to kg/s to be used as a CFD boundary condition.

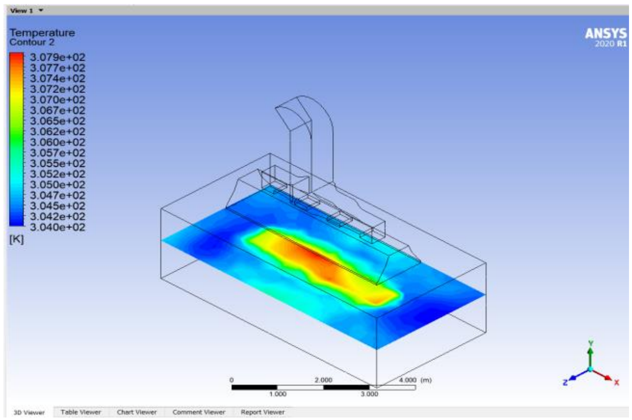

Fig -6 (a): Temperature contour of kitchen with ventilation system- Medium duty

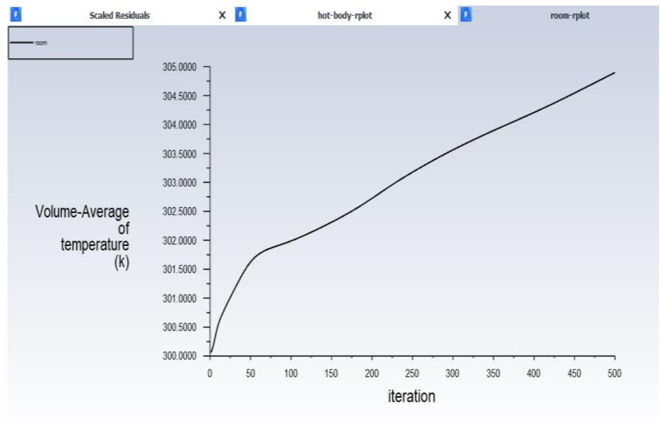

Fig -6 (b): Volume average temperature rise of Kitchen

With ventilation system, the temperature in the kitchen rose to 304.9 K from 300K seen in Fig -6 (a). Fig -6 (b) shows temperature of fryer decreased up to 467.22 K.

3.4 With Ventilation System- Heavy Duty

Heated air carries the temperature of the surrounding air with it. CFD simulation is used to assess the temperature behavior of the maximum flow rate, which extracts contaminants and heat. Because single island canopy requires a higher flow rate than wall mounted canopy. Because the fryer is away from the wall in the kitchen, a single island canopy is employed for mechanical extract ventilation. Boundary conditions of heavy load category are used:

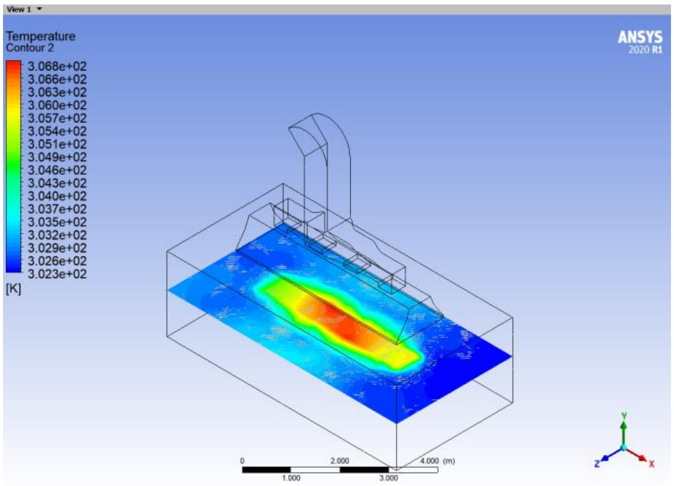

Fig -7 (a): Temperature contour of kitchen with ventilation system- Heavy duty

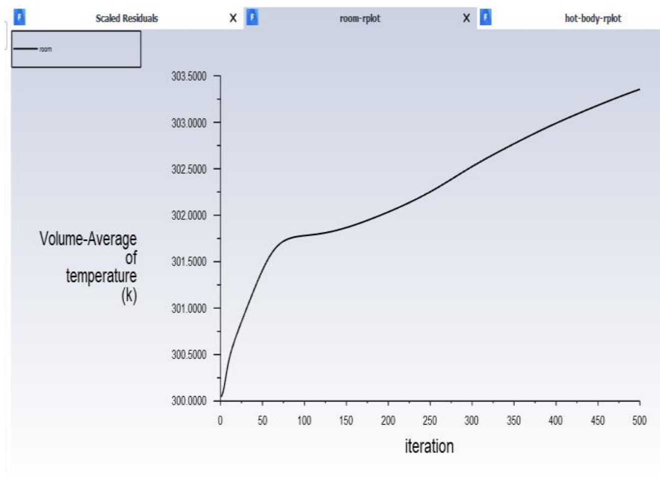

Fig -7 (b): Volume average temperature rise of Kitchen

With ventilation system, the temperature in the kitchen rose to 303.36 K from 300K seen in Fig -7 (a). Fig -7 (b) shows temperature of fryer decreased up to 467 K.

Table -2: Temperature Variation Observed in CFD Simulation

Commercial Kitchen System	Initial Temperature of kitchen (K)	Final Temp. using CFD	Temperature of Fryer (K) Initial Temp = 468 K
Without Ventilation	300	311.54	463.52
With Ventilation System – Medium Duty	300	304.9	467.22
With Ventilation System – Heavy Duty	300	303.36	467

4. DISCUSSION

The indoor temperature conditions of commercial kitchens that do not employ a ventilation system are the worst, according to the measurement findings. Calculating flow rates for medium and heavy workload cooking for a mechanical extract ventilation system yields better results. Without a ventilation system, the temperature rises to 11.54 0C, creating an unpleasant interior atmosphere. After implementing a ventilation system, outflow assessed by medium and heavy duty categories decreases temperature by 6.65 0C and 8.19 0C, respectively, compared to before installation. Instead of boosting the temperature up to 11.54 0C, the medium and heavy duty outflow systems boosted the temperature to 304.9 K and 303.36 K, respectively. In order to reduce the cost of single island canopy one need to do some changes in commercial kitchen by shifting whole setup near wall so that wall mounted canopy gets suitable for the system. Because a wall-mounted canopy requires less exhaust flow rate, the overall cost of the instruments is reduced. As the flow rate decreased, the number of filters required decreased, as did the required blower capacity, which may have lowered the overall setup cost. Installing fire safety devices such as water spray or carbon dioxide spray can help to enhance the safety of a setup. Color variation also be shown in the temperature contour depicted in the CFD simulation. The temperature around the fryer setup varies the most, up to 11.54 0C. As a result, it suggests that the tenant is being impacted by an unhealthy atmosphere.

5. CONCLUSIONS

The thermal comfort and indoor air quality of a commercial kitchen were measured in this study. The commercial kitchen's temperature environment had been very non-uniform. To optimize the design parameter, CFD simulations were performed. A commercial kitchen ventilation system is built with a canopy, baffle filter, blower, and ducting system. The study yielded the following outcomes:

In CFD simulation for cooking without a ventilation system in a typical commercial kitchen, the air temperature may rise 11.54 0C. By estimating exhaust flow rates, the ventilation system is constructed. The medium and heavy duty outflow systems increased the temperature to 304.9 K and 303.36 K, respectively, rather than 311.54 K, which is lower than the system without ventilation.

The dimensions of canopy and exhaust flow rate of 4.65 kg/s is suited for commercial kitchens and falls within the heavy duty category. CFD simulations shows the installed system lowers the temperature of the kitchen by 8.19 0C. As a result, a comfortable interior atmosphere is created. The size and equipment chosen for the ventilation system are appropriate for design.

REFERENCES

[1] Sumei Liu (2020).Improving indoor air quality and thermal comfort in residential kitchens with a ventilation system. Building and Environment. Volume 180, August 2020, 107016. https://doi.org/10.1016/j.buildenv.2020.107016

[2] Wei-Biao Y. (2017). Design method and modeling verification for the uniform air Flow distribution in the duct ventilation. Applied Thermal Engineering 110 (2017),573–583. https://doi.org/10.1016/j.applthermaleng.2016.08.177

[3] Zhenlei Chen (2020).Air quality and thermal comfort analysis of kitchen Environment with CFD simulation and experimental calibration. Building and Environment 172(2020) 106691. https://doi.org/10.1016/j.buildenv.2020.106691

[4] Zeren Jiao (2019).Optimization of dilution ventilation layout design in confined environments using Computational Fluid Dynamics (CFD).Journal of Loss Prevention in the Process Industries 60 (2019) 195–202.https://doi.org/10.1016/j.jlp.2019.05.002

[5] J.J. McArthur (2020). Rethinking ventilation: A benefit-cost analysis of carbon Offset increased outdoor air provision. Building and Environment 169 (2020)106551. https://doi.org/10.1016/j.buildenv.2019.106551

[6] Qian Li (2019). Flexible real-time ventilation design in a subway station Accommodating the various outdoor PM10 air quality from climate change variation (2019).Building and Environment 153 (2019) 77–90. https://doi.org/10.1016/j.buildenv.2019.02.029

[7] Lili Ji (2019). Long-term performance of fibrous ventilation/air-cleaner filters for particle Removal. Building and Environment 160 (2019) 106222. https://doi.org/10.1016/j.buildenv.2019.106222

[8] Haohan Sha. (2020).Investigation of mechanical ventilation for cooling in high - Rise buildings. Energy & Buildings 228 (2020) 110440 https://doi.org/10.1016/j.enbuild.2020.110440

[9] K. Ratna Kumari .Design And Drafting of HVAC, Central Air Conditioning System for an Office Building. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), e-ISSN: 2278-1684, PP 44-50.DOI: 10.9790/1684 -16053044450.

[10] Pollard. (2005). DW/172 Specification for Kitchen Ventilation Systems. (Heating and Ventilating Contractors' Association). (First Edition 1999). (pp 7.29-39, 5-12). www hvca.org.uk

[11] Indian Standard, (2003). IS 3646, Code Of Practice for Interior Illumination, (General Requirements and Recommendations for Working Interiors). (Part 1). (pp 22).

[12] CPWD. (2017).General Specifications for Heating, Ventilation & Air- Conditioning (HVAC) Works. Government of India Publication, (Directorate General Central Public Works Department).Chapter 9. (pp-40,101-108,148-150).

[13] ANSI/ASHRAE/IES Standard 90.1-(2016). Performance Rating Method Reference Manual. Chapter 6, (pp-251).

[14] ASHRAE HANDBOOK. (2019**).** Heating, Ventilating, and Air-Conditioning APPLICATIONS, Chapter 34. (pp-34.14,18). www.ashrae.org

[15] ASHRAE Applications Handbook (SI). (2003**).**Kitchen Ventilation. Chapter 31. (pp-31.1- 31.19).

[16] CIBSE Guide B2. (**2016).**Ventilation and ductwork. Chapter 2. (pp 18-42,67- 68,100).ISBN 978-1

[17] Wang Shan K, Handbook of Air conditioning and Refrigeration. (2001) Second Edition. Chapter 17. (pp-17.28-30, 53). McGraw-Hill

[18] N. H. Wong (2007). Field tests on a grease trap effluent filter. ISSN: 1735-1472. Int. J.Environ. Sci. Tech., 4 (3): 345 -350.

[19] Industrial Ventilation. (1998). Local Exhaust Hoods. Chapter 3. (23rd Edition).(pp- 3-22).ISBN: 1-882417-22-4.

[20] ISHRAE Handbook. (2007). Air Ducts-Design, Material and Installation, (Chapter 2). (pp2.1-5).

[21] ASHRAE. (2017). Pocket Guide for Air Conditioning, Heating, Ventilation, Refrigeration Duct. Chapter (9th Edition). (pp-64,).ISBN 978-1-939200-85-3

[22] Asmuin, N. (2014). Simulation of water mist spray for commercial kitchen Ventilation (CKV) system using Ansys-CFD. Applied Mechanics and Materials. Vol. 660. pp 704-708. Doi.10.4028

[23] Manshoor, B. (2014). Optimizing of Makeup Air Performance for CommercialKitchen Ventilation Improvement. DOI: 10.1051/ matecconf /2014 1303002.

[24] Livchak, Andrey. (2003). the Facts. Mechanical Grease. Kitchen Ventilation. A Supplement to ASHRAE Journal. 14-17.

[25] NFPA 96. (2016).Ventilation control and Fire Protection of Commercial Kitchen. (Chapter 5). www.NFPA.org/96

[26] Bhatia, A. (2012). Fundamentals of Kitchen Ventilation. Hood Construction. Pp9.

[27] Angui, Li. (2019). Kitchen Pollutants Control and Ventilation. Springer Publication. pp-253-260. https://doi.org/10.1007/978-981-13-6496-9

[28] Koch. P. (2008). Equivalent diameters of rectangular and oval ducts. Building Serv. Eng. Res. Technol. 29, 4. pp. 341–347. www.bse.sagepub.com

[29] ANSI/ASHRAE Standard 154-2003. (2003). Ventilation for Commercial Cooking Operations. ISSN 1041-2336. pp-5.6.

[30] DW/144. Specification for Sheet Metal Ductwork. (2013). Building & Engineering. Services Association. Second Edition. Chapter 3. pp- 41-45,50.

[31] Arthur A Bell. (2000). HVAC Equations, Data and Rules of Thumb. McGraw-Hill. Chapter 18, pp-140-141. ISBN 0-07-136129-4.