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Thermal Environment Evaluation in Commercial Kitchens of United States

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Abstract

The indoor climate in commercial kitchens is often unsatisfactory and the working conditions can have a significant effect on employees' comfort and productivity. The differences between type (fast food, dining, etc.) and climatic zone can have an influence on the environment conditions and on the employees´ perception of kitchens thermal conditions. Moreover, size and arrangement of the kitchen zones, appliances, etc., complicate further an evaluation of the indoor thermal environment in kitchens.

The on field physical measurements together with the occupants´ feedback is the effective way of defining the values of thermal comfort parameters in kitchens. It can also help to evaluate if the standardized methods are applicable for such non-uniform environment, like commercial kitchens.

By using an established method and procedure for evaluating the indoor thermal comfort in commercial kitchens more than 100 kitchens environments in the United States were investigated in summer and winter.

Results show the influence due to type of kitchen (fast food, casual, etc.) and climatic region. Physical measurement confirmed that communally the workers are exposed to a warm or hot environment, with temperature even higher than the ones that can be supported by the human physical strength.

PMV/PPD index resulted not suitable for application in commercial kitchens. Kitchens environments with a big range of operative temperature were investigated.

Keywords –kitchens environment; thermal comfort; thermal acceptability

1. Introduction

A commercial kitchen is a unique space where heating, ventilation, and air conditioning (HVAC) applications operate within a single environment (exhaust, supply, transfer, air conditioning, and so forth). In a so complicate environment as the commercial kitchen often the indoor climate is unsatisfactory and the working conditions can have a significant effect on employees' comfort and productivity.

Today, there are no specific regulations or even parameters to guarantee that the thermal conditions in such environment are either comfortable or cost-effective.

The restaurant industry in the United States is the nation's second largest private sector employer with a workforce of nearly 13 million projected to increase at 14.1 million in the next decade. Nearly one in ten working Americans work in a restaurant (National Restaurant Association (NRA)) [1]. For countries such as the United States, where one of the largest employee sectors is in the restaurant industry, the wellbeing of the employees became one of the main issues.

As a result of the high level of radiant heat produced by the equipment, the indoor environmental quality of a commercial kitchen space may often be unsatisfactory. Low productivity, higher turnover, and high absence rates are direct results of uncomfortable commercial kitchen conditions caused by excess heat.

In general, comfort criteria are expressed in international standards such as ASHRAE 55-2010 [2] or ISO EN7730-2005 [3]. But are these standardized methods applicable for such environments as commercial kitchens?

Therefore, there is a need to study the indoor environment in commercial kitchens and to establish standardized methods and procedures for setting criteria that have to be met for the design and operation.

Based on standardized methods [2-3] and on a pre-test pilot procedure of collecting data in kitchens [4-5], physical data of the kitchen environment and subjective reactions of the occupants-employees were collected during onsite measurements performed in 105 and 104 kitchens located in 9 States of US during summer and winter season.

The analyzed data show that the general evaluation criteria for thermal comfort applied in commercial kitchens is inadequate and unsuitable for practical application. Some results obtained by analyzing the recorded physical parameters for the global thermal conditions in commercial kitchen are here presented. Comparisons of thermal environment due to type of kitchen (fast food, casual, institutional) and climatic region are here reported.

2. Evaluation of the Thermal Environment in Commercial Kitchens

The indoor thermal climate has a significant impact on a worker's comfort, and unsatisfactory thermal conditions within a work environment will inevitably affect performance and productivity, and can pose occupational safety hazards for employees.

Thermal comfort, one of six elements that influence the indoor environmental air quality (IEQ) of a given space, is defined as a "condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation," (ASHRAE 55 [2]); a definition that has been converted into specifications based on physical parameters.

One of the most widely used indices for assessing thermal environments is the predicted mean vote (PMV) index (Fanger, 1970 [6]), used to predict the mean value of the overall thermal sensation (TS) of a large group of people as a function of six main parameters: air temperature, mean radiant temperature, relative humidity, air velocity, activity level, and thermal resistance of clothing. The use of PMV index is recommended only for values between -2 and +2 and when the main parameters are within a certain range of value.

In practice, it is not always feasible to determine optimal thermal comfort (i.e., PMV=0) and it should be always considered a certain percentage of people that feel unacceptable the thermal environment (percentage of dissatisfied (PD)). Thermal dissatisfaction may be caused by an overall thermal sensation that is too warm or too cold or by a local thermal discomfort due to draught, vertical temperature gradient, radiant asymmetry, or warm or cold floors.

For many years the international standard organisation (ISO) and ASHRAE have been developing standards for the indoor thermal environment. ASHRAE has mainly developed standards for moderate thermal environments (ASHRAE 55 [2]) while ISO standards cover the range from cold stress to comfort to heat stress (ISO EN 7730 [3], ISO EN 7933[7], ISO EN 11079 [8]).

As the commercial kitchen environment presents different conditions than those studied earlier a measuring procedure needed to be established focusing in particular on the processes characterizing the kitchen space.

Thermal conditions of the working environment in commercial kitchens are primarily driven by radiant heat that directly impacts the employees. Moreover, appliances, size and arrangement of the kitchen zones, number of employees, variable environmental conditions during business hours, etc., complicate further an evaluation of the indoor thermal environment in kitchens, which is not straightforward.

Many of the available studies in commercial kitchens have focused mainly on air-conditioning and ventilation systems (e.g. [9]).

Moreover, Pekkinen and Takki-Halttunen (1992 [10]) showed that the best thermal conditions in kitchens exist when the supply air unit is placed in the ceiling next to the exhaust hood, so that a supply air unit compensates for the high levels of radiant heat. However their results are based on a laboratory study where the thermal comfort conditions are evaluated in comparison with the resulted physical parameters of Fanger (1970) [6] and Fanger et *al.* (1985) [11] measured in indoor spaces like offices.

Another study, conducted concerning the commercial kitchens environment, indicates that the areas on the body that have the greatest exposure to temperature differences are in the upper part, such as the chest and facial areas, and those between a height of 1.5 m and 1.8 m from the floor ([12]). Additionally, the most critical work is at the cooking line, which produces the largest heat gains in the space, and where the workers are exposed to the highest temperatures.

3. Data Collection

Data collection includes several types of measurement: external temperature and humidity, HVAC-system performance (supply, make-up, and transfer air temperature and relative humidity), indoor (thermal) environment, physiological and subjective evaluation.

As earlier mentioned the commercial kitchen environment presents different thermal conditions than those studied earlier. Consequently, based on standardized methods and on limited pre-test pilot measurements, performed in 4 Danish commercial kitchens during different time of the working day and during high working activity demand, the procedure for evaluating the indoor thermal environment in commercial kitchens was established focusing in particular on the processes characterizing the kitchen space. Therefore three different kitchen zones (cooking, food preparation, and dish-washing) were measured; these being considered to have different thermal conditions in the commercial kitchen. Subsequently, the measurements were gathered according the procedure and the instruments described in Simone and Olesen (2012) [4]. The main part of the established procedure is represented in Figure 1 and consists of:

- ✓ Long term measurements of t_o, t_a, and *RH* over one week at three work locations: cooking, dish-washing, and food preparation zone.
- ✓ Short-term on-site measurements of subjective (evaluation of activity level and clothing insulation) and physical parameters (t_a, t_o, *RH*, and v_a). The physical data are recorded at three different heights (0.1 m, 1.1 m, and 1.7 m) and at three working locations (cooking, dish-washing, and food preparation).
- ✓ On-site survey of occupants' subjective reaction to the indoor environment contemporaneously to the recording of the physical measurements.
- ✓ General survey of background information employees and their evaluation of the working conditions.

4. Measurements

Physical parameters and subjective reactions in kitchens were collected from 105 and 104 commercial kitchens, respectively in summer and in winter, located in 9 metropolitan areas of different climate zones (defined by ASHRAE 169/2006 [13]) of United States (see Table 1).

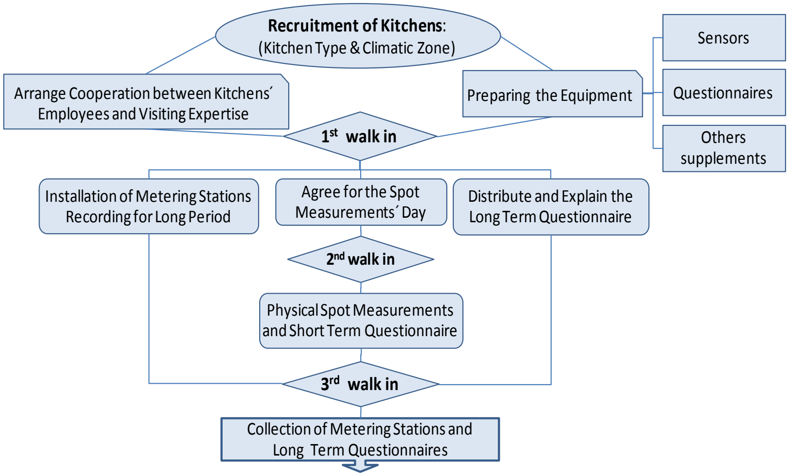

Fig. 1. Sketch of Thermal Evaluation Procedure for Commercial Kitchens

Table 1. Number of Measured Kitchens in Different Metropolitan Areas of US

Climate Zone	US City	Summer	Winter
1 - Moist	Miami	12	12
2/3 Moist	Atlanta	12	12
2/3 Dry	Phoenix	12	12
4 - Marine	Seattle	14	14
4 - Moist	Nashville	9	8
4 - Moist	Washington DC	10	10
5/6 Moist	NYC	11	10
5/6 Dry	Las Vegas	12	13
7 - Moist	Minneapolis	13	13
Sum of Kitchen		105	104

Moreover, full scale data, including both short and long term measurements (S&L), were collected in 39 and 35 kitchens in summer and winter.

Additionally, the enrolled kitchens were grouped, as shown in Table 2, mainly in relation of their operational restaurant performance, into one of the three following categories:

- Quick service restaurant (QSR);
- Casual dining restaurant;
- Institutional.

Table 2. Number of Measured Kitchens Types in US

Kitchen Type	Summer		Winter	
	S&L	All	S&L	All
QSR	11	53	11	53
Casual	6	14	6	11
Institutional	22	38	18	40
Sum	39	105	35	104

5. Physical Measurements—Short term

Derived from the detailed spot measurements, the average values of the measured thermal parameters by type and kitchen zones are reported in Tables 3 and 4. Table 3 introduces the averages of all thermal environmental parameters measured/estimated per kitchen type and areas needed to calculate the PMV index.

Table 3. Average of Measured Physical Parameters by Kitchen Type and Thermal Zone

ALL Kitchens		t_o	t_a	t_{mr}	RH	v_a	I_{cl}	activity
Kitchen Type	Kitchen Zone	[°C]	[°C]	[°C]	[%]	[m/s]	[clo]	[met]
Casual	Cooking	31.3	29.2	35.2	36	0.41	0.7	4.0
	Preparation	23.9	23.5	24.4	34	0.29	0.7	3.4
	Dishwashing	21.8	21.8	21.9	42	0.25	0.7	3.5
Institutional	Cooking	30.9	28.5	34.6	30	0.39	0.7	3.9
	Preparation	23.6	23.2	24.0	36	0.27	0.7	2.9
	Dishwashing	24.8	24.2	25.4	44	0.26	0.6	3.2
QSR	Cooking	26.3	25.3	27.8	39	0.28	0.6	3.1
	Preparation	25.9	25.4	26.5	38	0.22	0.6	2.6
	Dishwashing	19.8	19.1	20.4	42	0.14	0.6	2.4

Data show that for casual and institutional kitchens the cooking zone was the warmest.

However for QSRs the differences between cooking and food preparation were very small. This is due to the cooking zone and preparation areas being close to each other in these smaller kitchens and also due to a presence of more appliances in the preparation zone needed to keep the cooked food warm.

Table 4 reports the average values over the type of kitchens of PMV and operative temperature for each climate zone in summer and winter. Even if the average PMV values are lower than the limit +3, several individual values were outside the PMV range, indicating the non-applicability of the PMV index.

The PMV differences between climate zones during summer are not significant. On the other hand, the operative temperatures show larger differences. Climate zones 1-Moist, 5/6-Moist, and 7-Moist are significantly warmer than climate zones 4-Marine and 5/6-Dry. During winter, the PMV-index is significantly lower for climate zone 5/6-Moist, while the operative temperature is significantly lower for climate zone 4-Marine (see Table 4).

In all climate zones, the PMV index is significantly lower during winter than during summer, and it is not the same for operative temperature. For the climate zones 2/3-Dry, 2/3-Moist, 4-Moist, and 5/6-Dry, there are no significant differences between winter and summer.

Table 4. Representative Values of Physical Measurements by Climatic Zone and Season

Climate Zone	Summer		Winter	
	PMV (±SD)	t_o (±SD)	PMV (±SD)	t_o (±SD)
	[-]	[°C]	[-]	[°C]
1 - Moist	2.7±0.9	29.0 ±2.8	0.4±1	25.4±3.3
2/3 Moist	2±0.7	27.1±4.2	0.3±1.4	26.8±5.2
2/3 Dry	2.1±2	28.3±6.2	0.8±0.9	26.3±4.2
4 - Marine	2.5±0.7	23.9±1.5	0±0.6	20.5±2.7
4 - Moist	2.9±1.9	26.6±5.3	0.7±1.1	25.8±5.1
5/6 Moist	2.9±1.1	30.3±5.3	-0.8±1.3	23.1±4.5
5/6 Dry	2.1±1.7	24.9±6.1	0±1.2	24.0±4.2
7 - Moist	2.7±0.9	29.7±3.9	-0.2±0.9	24.3±2.5

In Table 5 the recorded average of PMV index and operative temperature are reported for the three kitchen types for summer and winter.

Table5. Representative Values of Physical Measurements by Kitchen Type and Zone

Kitchen Type	Kitchen Zone	Summer		Winter	
		PMV (±SD)	to (±SD)	PMV (±SD)	to (±SD)
		[-]	[°C]	[-]	[°C]
Casual	Cooking	4.9±0.8	34.9±1.7	1.0±1.2	27.4±3.5
	Preparation	2.4±0.8	28.7±1.6	-0.2±1.1	21.4±2.8
	Dishwashing	2.0±0.4	28.7±0.1	-0.2±0.7	19.5±3.1
Institutional	Cooking	3.7±1.4	30.9±5.3	1.6±0.9	30.4±4.8
	Preparation	1.7±0.9	24.0±3.7	0.2±0.7	23.1±3.1
	Dishwashing	2.1±1.1	24.7±2.6	0.3±0.8	24.9±2.8
QSR	Cooking	2.8±0.6	29.1±2.8	-0.2±1.0	23.6±3
	Preparation	1.8±0.5	26.6±2.6	-0.4±0.9	24.8±2.9
	Dishwashing	1.2±n.a.	21.4±n.a.	-2.3±1.5	19.4±3.3

It is clear that the PMV index in the cooking zone is much higher than the range where the index can be used. For casual and institutional kitchens, the cooking zone has a significantly higher PMV index and operative temperature; with no significant difference between preparation and dishwashing zone. For QSR kitchens, there was no difference between cooking and preparation zone. The dishwashing zone was colder, but due to very few data, the confidence interval is very large. In winter the PMV index is within the range for application of the index. For all kitchen types and zones, the winter kitchen temperatures were colder than the summer.

Measured vertical temperature profiles, in summer and winter, are shown in Figure 2 for a casual kitchen type. The results are in agreement with Livchak (2005) conclusions [12]. They also show the high vertical temperature difference, higher than the acceptable limit of ΔT=3°C [3].

The warm/hot environment in the cooking area exposed the workers to temperatures higher than 31 °C that is the maximum exposure temperature proposed by Weihe (1987) [14]. So high temperatures cannot be supported by the human physical strength and, besides, the occupant health can be affected.

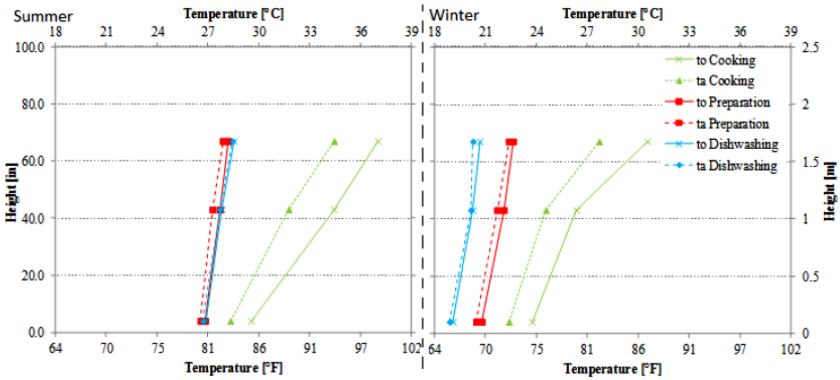

Fig. 2. Vertical Profile of Average Temperatures Distribution for Casual Kitchen

An example of the long-term measurements is shown in Figures 3 for a casual dining restaurant, in winter, located in 4-Moist climate zone. Air and operative temperatures are shown as broken and solid lines respectively. During the 24-hour data recording period, the temperature variation that directly influenced employees' thermal comfort occurred during assumed operating hours from 10:00 a.m.to 10:00 p.m., represented by the shaded areas.

Considerable diurnal temperature variations in the cooking line occurred, rising from circa 24 °C to almost 38 °C during the kitchen operating time. The temperature in the food preparation line and in the dishwashing area had a daily temperature variation in the ranges of 22-27 °C and 22-25 °C, respectively, during working hours. Thermal radiation from the hot appliances raised the operative temperature by an additional 5.8 °C.

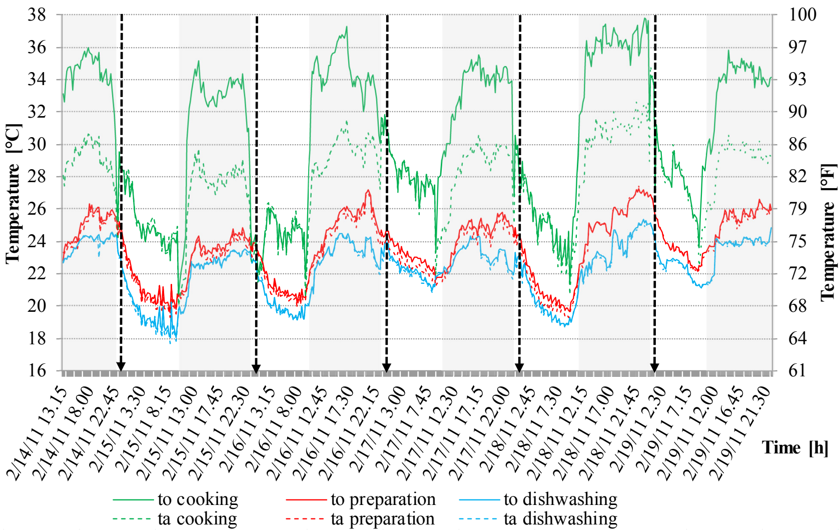

Fig. 3. Air & operative temperature (t_a & t_o) variations in different kitchen zone in winter

An overview of the performed investigations, in summer and winter, related to the kitchens physical parameters is illustrated in Figure 4. A wide range of operative temperatures were recorded.

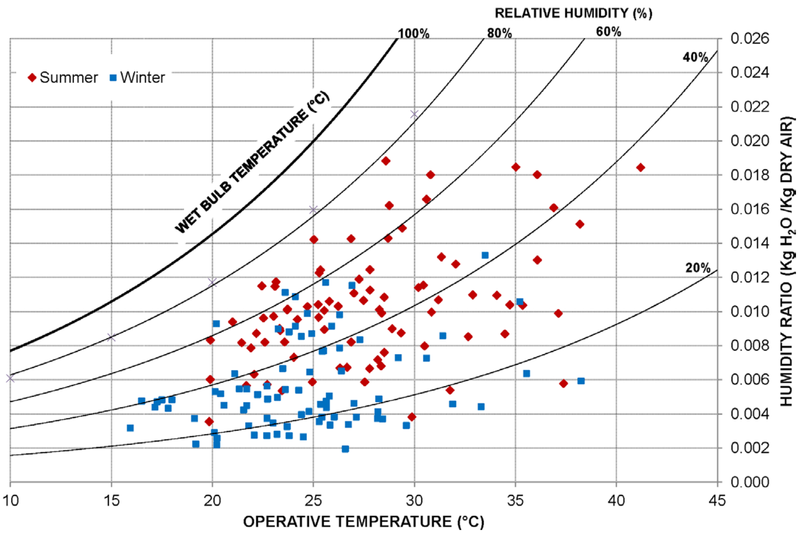

Fig. 4. Air & operative temperature (t_a & t_o) variations in different kitchen zone in winter

6. Conclusions

The results give a benchmark for the thermal environment in commercial kitchens, and a database has been established. The present paper includes only few results of the analysis of the collected data. The influence of climate zone, summer compared to winter seasons, and type of kitchens is reported. The PMV/PPD index is not suitable for application in commercial kitchens. Very often the measured index is outside the recommended range of ±2. This is mainly due to the combination of high activity levels and high air temperatures.

This study has shown that there is a need to establish a method (standard) to evaluate working environments ranging between thermal comfort and heat stress. In general, the method used (physical and subjective measurements) to evaluate the thermal environment in commercial kitchens can be recommended for future studies and for evaluating future products.

Acknowledgement

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