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Analyzing Indoor and Outdoor Heat Index Measurements in Kitchens

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by

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DEDICATION

This paper is dedicated to my amazing parents Michael and Lesley Welch. Thank you both for always loving and helping me along this long, long journey. You both have allowed me to make my own decisions and choices and have always accepted me for who I am. For that, I will be forever grateful.

This paper is also dedicated to my incredible boyfriend Kevin Di Nardo who has not only supported me through this Master's program but has supported me these past ten years through all of my trials and tribulations. Thank you for always showing me the light, particularly when I struggled to find it within myself.

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ABSTRACT

Occupationally induced heat-related illnesses (HRI) can play a huge part in the lives of employees working within outdoor kitchens. According to the National Institute for Occupational Safety and Health [NIOSH] (2016), “exposure to heat can result in injuries, disease, reduced productivity and death”. When working in outdoor environments, it is important to limit exposure time of direct sun or heat as well as to stay properly hydrated. One way to ensure limited occupational heat exposure is by measuring the Heat Index of the worker's environmental conditions.

The purpose of this study is to determine whether there was a difference between the indoor and outdoor Heat Index measurements among various kitchens.

Multiple locations within eight, freestanding, take-away service kitchens were sampled over a period of three days. A 3M QUESTemp 46 Heat Stress Monitor was used to sample the outdoor and indoor environmental conditions, specifically capturing the indoor Heat Index measurements. The outdoor Heat Index was reported with meteorological data from Weather Underground linked to the National Weather Service.

Multiple statistical analyses were performed to understand and explore the relationships between or among the difference of indoor to outdoor Heat Index measurements, as well as kitchen production levels and forced air ventilation. The results showed that higher production kitchens had a significantly greater increase in Heat Index compared to low production and high production kitchens with forced air ventilation. Due to the small

sample size of this study, it is recommended that future efforts to compare indoor and outdoor Heat Index measurements for kitchens include a larger sample size of both kitchens and locations.

INTRODUCTION

Employees working in hot environments, such as kitchens, may be at a higher risk of heat related illness (HRI). Heat stress can be influenced, and subsequently modified or reduced, by considering factors such as the workers' metabolic heat production or even by varying heat exchange processes like evaporation, radiation or convection (NIOSH, 2016). Through the use of engineering controls like forced air ventilation or capturing heat from the heat producing equipment like kitchen cooktops or stoves, these different forms of heat exchange can be modified. In addition to engineering controls, administrative controls can also be used to limit a worker's exposure time through rest and work cycles, as well as reducing the metabolic workload an employee exerts (NIOSH, 2016).

Based on the U.S. Natural Hazard Statistics data available through the National Weather Service National Oceanic and Atmospheric Administration, the average number of fatalities per year over the past 30 years related to heat is 134. In 2017 alone, there were 107 fatalities attributed to heat. According to the Healthcare Cost and Utilization Project (HCUP) Nationwide Inpatient Sample (NIS), between 2001 to 2010, of the 73,180 HRI hospitalizations, 1,356 were fatal. While many of these deaths were due to classic heat stroke, the occupationally-related fatalities follow a similar trend.

The Wet Bulb Globe Temperature (WBGT) is the environmental index used by NIOSH and the ACGIH to assess heat stress exposures. The Heat Index (HI) maps closely to WBGT and can be used to assess differences in outdoor environments or environments heavily influenced by the outdoor conditions. HI approximates equivalent environments in terms of net heat exchange and considers both relative humidity and air temperature.

The purpose of this study is to determine whether there was a difference between the indoor and outdoor Heat Index measurements among various kitchens.

LITERATURE REVIEW

Studies that focus on analysis of Heat Index as an appropriate form of measuring occupational environments for heat stress were the primary source of literature reviewed. One study looked to see whether Heat Index is a suitable indication to screen for occupational heat stress. The second study focused on using National Weather Service ambient data to measure heat stress. Another study looked at various commonly used Heat Index algorithms to determine whether different Heat Index algorithms produce similar Heat Index values.

The first study that was reviewed, examined whether the Heat Index and Adjusted Temperature can be used as a screening tool for occupational heat stress exposures. The study calculated Wet Bulb Globe Temperature inside ($WBGT_{in}$) and Wet Bulb Globe Temperature outside ($WBGT_{out}$) using dry bulb temperatures and relative humidity. The study showed in some situations where WBGT measurements are not available, surrogate measurements like Heat Index and Adjusted Temperature, are simply approximations and a subjective judgment needs to be made for radiant heat levels. Based on their results, the Heat Index and Adjusted Temperature are acceptable when used to screen or vet for occupational heat stress, rather than to make final determinations (Bernard 2015).

In the second study, ambient environmental data, WBGT, from the National Weather Service (NWS) was used to develop a prediction model to evaluate the heat stress of workers in an aluminum smelter. In addition to the predicted WBGT values, the study authors used the metabolic rate, and a task analysis to perform heat stress evaluations of different jobs. This work further supported the use of ambient heat data from the NWS in this analysis (Bernard 1996).

The third study was published in the *Environmental Health Perspective* Journal and looked at different algorithms commonly used in order to determine whether different Heat Index algorithms produce similar Heat Index values. The study investigated 21 separate Heat Index algorithms. The data used in the algorithms was from NWS Weather Undergrounds historical weather data, including mean air temperature, mean dew point temperature, and mean relative humidity. The first thing the authors looked at was whether the algorithm produced similar Heat Index values to Steadman's original apparent temperature. The algorithms were then correlated to each other to determine how similar each of the Heat Index results was. Their findings showed that many of the algorithms did, in fact, produce Heat Index values similar to one another, suggesting regardless of which Heat Index algorithm is used, the results will be comparable (Anderson 2013).

METHODS

The analysis that follows was conducted using data gathered in eight separate kitchens over a period of three days. The kitchens were all operated by the same entity and were chosen to reflect production volume. Kitchens are either high production, meaning a constant, and heavy flow of food production or they are considered low production, meaning a slow, and irregular flow of food production. The quantity of food sold during the times of sampling was used to determine production levels.

While sampling, there were roughly the same number of workers within each high production kitchens, as well as roughly the same number of workers in each low production kitchens. Not all eight kitchens were sampled at multiple times throughout the day, but similar locations within the kitchens were sampled. Locations were similar based on equipment surrounding the area as well as employee’s job tasks.

Table I illustrates the factors included in the analysis; kitchen production levels, if the kitchen had ventilation present, and the number of locations sampled within each kitchen.

Table I. Characterization of Kitchens and Sampling Nodes

Kitchen	Production Level	Ventilation Present	N Locations Sampled
K1	High	No	4
K2	High	No	4
K3	High	No	4
K4	Low	No	1
K5	Low	No	1
K6	Low	No	1
K7	Low	No	1
K8	High	Yes	1

The sampling within the kitchens was performed using a 3M QUESTemp 46 Area Heat Stress Monitor. Sampling included the wet bulb temperature, dry bulb temperature, globe temperature, WBGT inside, relative humidity percentage and the inside Heat Index. An electronic sensor check, or calibration, was performed both before and after each kitchen was sampled. A verification module, Quest model 053-923, was used to check the operation of the QUESTemp's wet bulb, dry bulb, and globe. Per the manufacturer, 3M, the purpose of performing this electronic sensor check was to verify that the electronic components are within a specific range with known values and a known source. The temperature tolerances were within +/-0.5°C, as recommended per the manufacturer.

For each environmental measurement included in this analysis, the indoor Heat Index, as described above, was measured along with compiled information about the abovementioned attributes for each kitchen; high production or low production, ventilation present or no ventilation present. These attributes were then used in statistical analysis to determine whether they had a significant impact on occupational heat stress exposure. These attributes were utilized because of the impact they would most likely have on employees.

In addition to measuring the inside Heat Index, the outside Heat Index measurements were assigned using historical data from the Weather Underground website, wunderground.com. Weather forecasts on the Weather Underground website are generated from the National Weather Service National Digital Forecast Database.

RESULTS

Basic statistical measurements for all kitchens are reported below in Table II. Table II shows the measured Heat Index (HI) inside the kitchen, historical Heat Index measurements for outside of the kitchen, as well as the difference between in the indoor and outdoor Heat Index for each location.

Table II. Heat Index (HI) Measurements by Kitchen Location

Kitchen	Location	HI Inside (°C)	HI Outside*(°C)	∆HI (°C)
K1	L1	35.0	26.8	8.2
	L1	37.8	30.7	7.1
	L1	29.3	25.3	4.0
	L2	30.0	26.8	3.2
	L2	34.4	30.7	3.7
	L3	31.1	26.8	4.3
	L3	37.8	30.7	7.1
	L4	34.4	26.8	7.6
	L4	38.9	30.7	8.2
K2	L1	34.4	26.8	7.6
	L1	35.0	30.7	4.3
	L2	33.9	26.8	7.1
	L2	35.6	30.7	4.9
	L3	33.3	26.8	6.5
	L3	36.7	30.7	6.0
	L4	34.4	26.8	7.6
	L4	38.9	30.7	8.2
K3	L1	34.4	30.7	3.7
	L2	35.0	30.7	4.3
	L3	35.6	30.7	4.9
	L4	33.3	30.7	2.6
K4	L1	27.5	25.9	1.6
	L1	28.3	26.5	1.8
K5	L1	27.8	25.9	1.9
	L1	28.0	26.5	1.5
K6	L1	28.0	25.9	2.1
	L1	27.9	26.5	1.4
K7	L1	30.0	25.9	4.1
	L1	28.5	26.5	2.0
K8	L1	26.5	25.4	1.1

** Measurements taken from Weather Underground historical data*

The two Heat Index measurements were used to compare and relate what environmental conditions employees were exposed to while working within a kitchen.

Figure 1 shows the floorplan for both a high production kitchen and a low production kitchen showing the relative size difference between high and low production kitchens, the number of employees working within a kitchen, and placement of heating equipment.

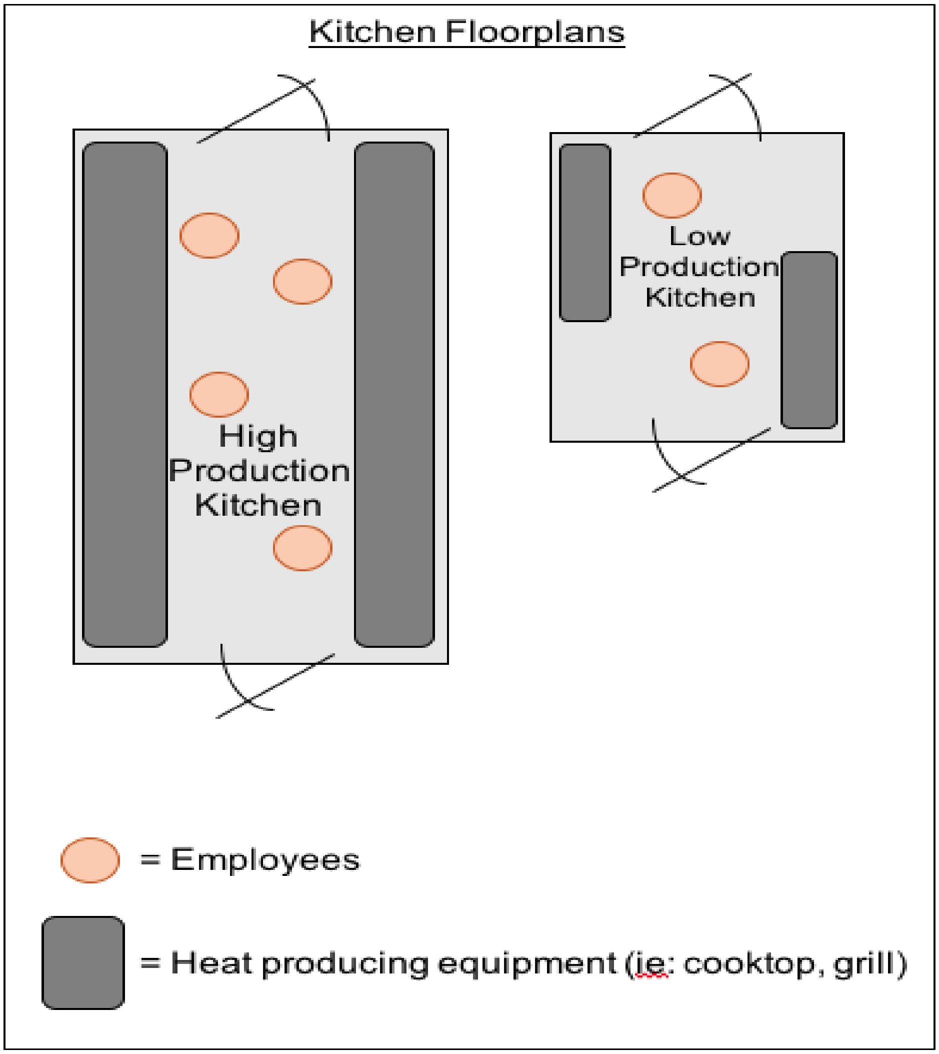

Figure 1. Kitchen Floorplans.

The first step to understanding the increase in heat moving from an ambient refence to the kitchen was to see if there were differences due to location inside the high production kitchens. A two-way analysis of variance (ANOVA) (kitchen by location) was performed. This ANOVA looked at only the larger, high production kitchens K1, K2 and K3 and the similar locations inside the kitchens L1, L2, L3 and L4 (see Figure 1). Table III and Figure 2 show the means for Kitchens K1, K2, and K3. There was a difference among kitchens ($p < 0.05$) where K2 was different from K3 based on a multiple comparison test. There were no differences among locations within the kitchens ($p = 0.24$).

Table III. Kitchen Mean Difference Heat Index Values

Kitchen	Mean ΔHI (°C)
K1	5.9
K2	6.5
K3	3.9

Figure 2 represents the mean Heat Index differences for the four locations (L1, L2 L3, and L4) of the three kitchens (K1, K2, and K3).

Kitchens were also classified as high and low production. A one-way ANOVA (production type at Location L1) was then used to compare ΔHI the high and low production kitchens and one high production kitchen with forced air ventilation. This ANOVA found a difference among types with $p = 0.001$. Table IV shows the mean ΔHI for high production kitchens without ventilation, low production kitchens without ventilation, and high production kitchens with ventilation. Figure 3 shows the mean difference between indoor Heat Index and outdoor Heat Index values at L1 for high production kitchens without ventilation, low production kitchens without ventilation, and high production kitchens with ventilation.

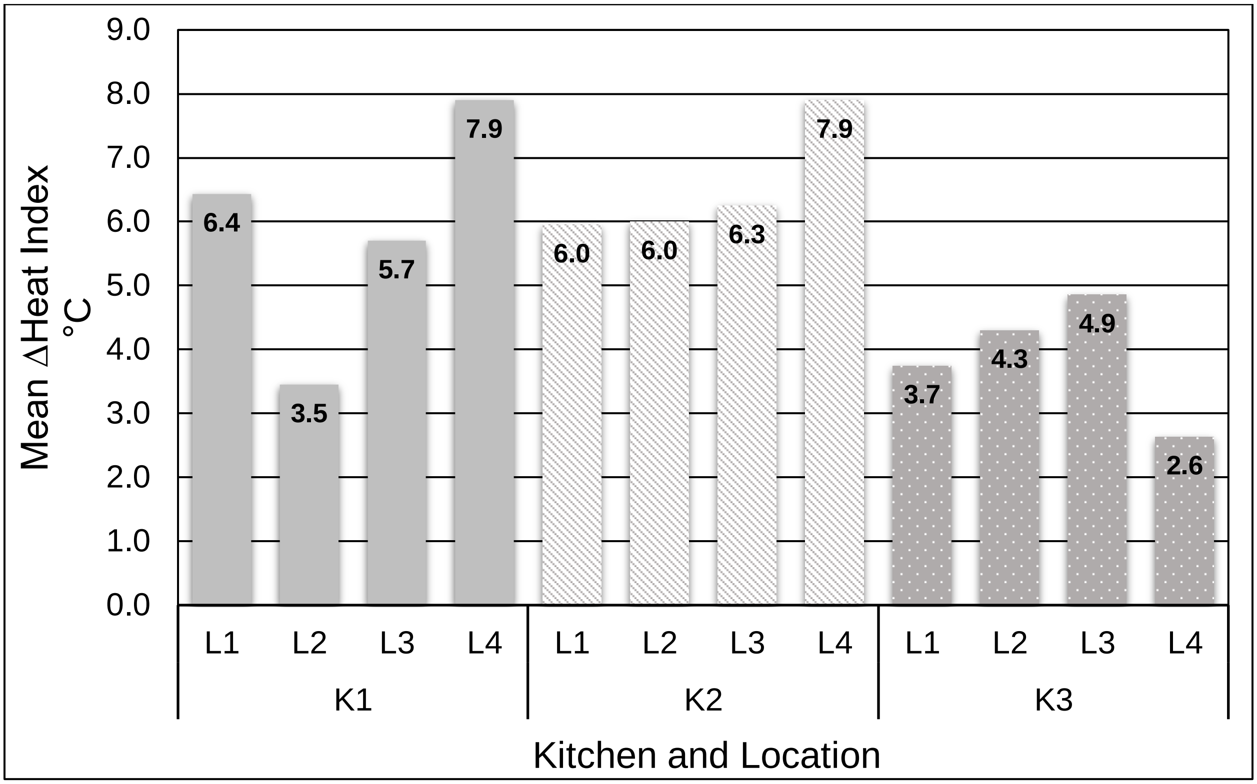

Figure 2. Mean ∆HI measurements, °C, for Kitchen locations.

Table IV. Kitchen Production Level Mean Heat Index Values

Kitchen Production Level	Mean ∆HI (°C)
High	5.82
Low	2.05
High**	1.10

** With forced air ventilation

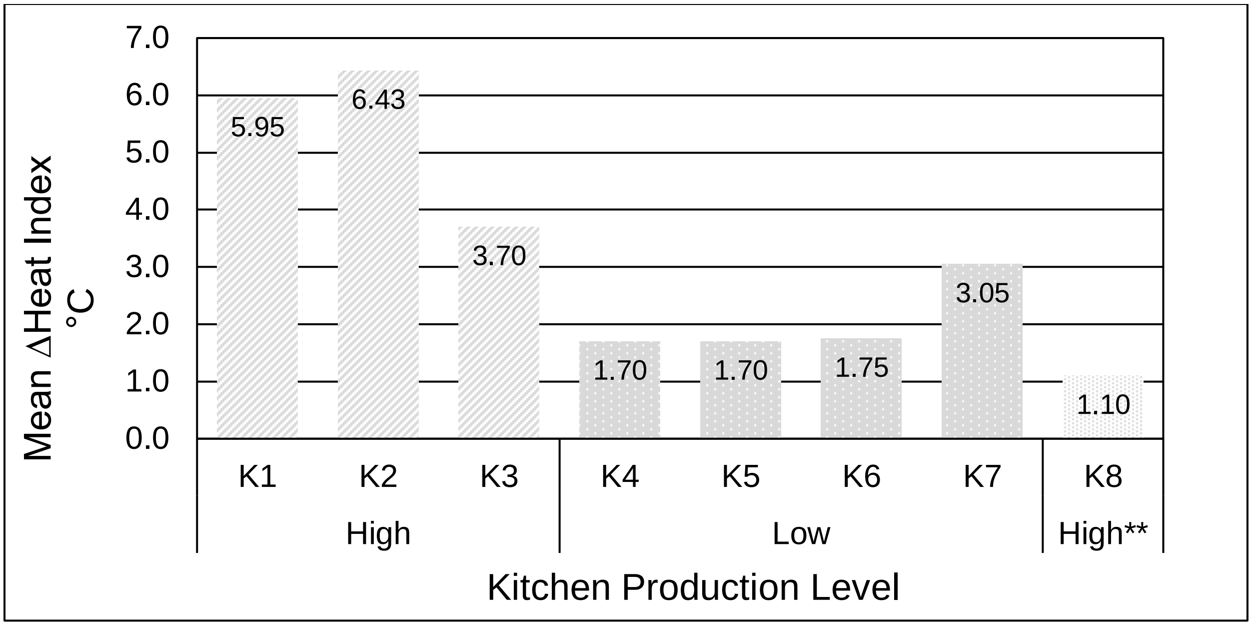

Figure 3. Kitchen production level compared to mean Heat Index
*** High production level with forced air ventilation*

DISCUSSION

The Heat Index was used to represent the environmental conditions and can be a good place to start when screening for occupational heat exposures. Measurements were taken inside the kitchen with the 3M QUESTemp including Heat Index. Ambient Heat Index based on a standard assessment by the National Weather Service was used to standardize the ambient conditions. The mean ΔHI values in Table II show that every data point collected had a greater Heat Index inside the kitchen than outside. This was expected because of the heat sources inside the kitchens.

The first step was to examine differences in location in the three high production kitchens by comparing K1, K2, and K3 over the four common locations, L1, L2, L3, and L4. There were no differences among locations within the kitchens, but there was a statistically significant difference among kitchens (2.5°C difference in ΔHI between K2 and K3). Besides random error, there may be systematic differences among the three kitchens that were not noted in this study. For instance, natural ventilation or shading may have influenced the results.

The next step was to consider differences due to production type. The results are illustrated in Table IV and Figure 3. When kitchen production levels were high, and no forced air ventilation was present, the mean difference between indoor and outdoor Heat Index was significantly higher than for kitchen production levels that were low with no forced air ventilation. For comparison purposes, a high production kitchen with forced air ventilation was included in the analysis. This kitchen design had a lower ΔHI than the other kitchens. K8 (high production with forced ventilation) suggests the value of forced air ventilation.

Another note about differing production levels is typically, the higher production kitchens had either fewer or smaller openings and windows, allowing less natural ventilation to flow through. The evidence suggests this lack of natural airflow could have been a contributing factor for the increased temperatures in the kitchens compared to outside the kitchens.

The use of just one location to compare kitchens was supported by the absence of differences among locations in the high production kitchens.

Despite all attempts to control for errors, it is possible that there were random or systematic errors made. One potential source of error could be caused by the use of the NWS historical weather data, which cannot account for local ambient conditions and differences among the local ambient conditions. Another source for potential error could have been equipment error if the calibration process was not followed perfectly. The most likely error to have been made would be the sample size was too small to get a complete picture or accurate understanding of how forced air ventilation within a kitchen impacts the occupational environment. When considering future work or follow up research, it is suggested that a larger sample size of both kitchens and number of measurements throughout the day be captured, performing outside Heat Index measurements instead of just inside measurements, as well as performing WBGT measurements for both inside and outside of the kitchens.

In conclusion, there are some differences among kitchens but the largest difference is due to production. High production kitchens are hotter than low production kitchens. It appears that the added heat from high production kitchens can be reduced by adding forced ventilation.

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