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HEAT EXPOSURE AND EFFECTS ON PRODUCTIVITY AT A GARMENT FACTORY IN PHNOM PENH, CAMBODIA - a pilot study

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Abstract, Executive summary

Workplace heat is a well known occupational health hazard and apart from serious heat stress effects on health and comfort, heat slows down worker's activities due to the physiological limits of the human body. This study in a garment factory in Cambodia is the result of a letter in 2014 from the first author of this report to Mr Karl-Johan Persson, the Managing Director of the Swedish multinational company H&M, alerting him to the potential health and productivity problems of workplace heat. This led to a proposal to study heat issues in a factory, and after a visit to Cambodia this study was implemented.

The study involved measuring hourly heat levels inside different departments of the factory and outside in the shade during several weeks in June, August and November, 2016, and analyzing the relationship between the heat levels daily estimates of productivity in the selected departments. The aim was to quantify the expected reduction of productivity as heat levels go up. A quantified relationship of this type would create an important basis for calculating the economic and health values of lowering intra-factory heat levels, and it would be an important input into estimations of the economic impacts of climate change and the value of mitigation and adaptation.

The results of the study showed that the heat levels, as measured by the common heat stress index WBGT, inside the factory are mostly in the range 26 to 29 degrees C, which are levels that are likely to make continuous intensive work difficult. This factory had an "air washer" cooling system, but the difference between the heat levels inside the factory and in the shade outside was very small. Thus, the existing cooling system is not very effective in creating a healthy and productive work environment. The results also show that the heat levels were similar in each of the three months studied, which indicates that these workplaces are likely to be affected by heat impacts almost any time of the year. The heat levels in the shade outside the factory are often somewhat higher than the reported levels at the nearby airport, suggesting that official weather station data may under-estimate heat at the factory.

The analysis of productivity loss during hot days was affected by other causes of productivity loss, and only a few of the departmental results could be analyzed quantitatively. However, the results indicate that the productivity loss can be substantial in certain jobs. Further, more focussed studies of productivity and comfort are recommended for days when other obvious causes of productivity loss are not in existence.

It is also recommended to carry out tests with improved air conditioning in certain parts of this factory in order to establish more definitely to what extent better cooling improves productivity and working conditions. In addition, garment factories in Cambodia or other hot countries would be good testing ground for air conditioning systems based on roof level solar panels or other renewable energy systems. Such systems would be an important contribution to local energy efficiency and reduced carbon footprint of garment factories.

Acknowledgements

First of all, many thanks to the management staff at the garment company who made arrangements locally for this study and thanks to the H&M staff who assisted at different stages. We are also grateful to Mr Persson at H&M, who agreed to the engagement of his company and suppliers to take part in the study. All the direct costs for the study incurred by the authors were covered by internal research funds available to the first author.

Background

In cooperation with H&M Corporation and a Cambodian supplier factory we were invited to develop this study of heat impacts on productivity in a garment factory. Our past research on the effects of heat on human physiology had indicated the possibility that significant reductions of productivity may occur in any type of physical work activity when heat exposure exceeds a certain level. The threshold for heat influence on productivity is not established with certainty and is likely to vary between different population groups and in different work situations. This study is labelled a pilot study as it was on a small scale, and focussed on testing methods aimed at better documenting any productivity effect and to use the results to develop advice on cooling solutions, if required.

Workplace heat as a threat to health and productivity

In a recent journal paper (Kjellstrom et al., 2017) it says: "Excessive heat while working is typically associated with ambient temperatures above 35º Celsius, and it creates significant occupational health risks as well as reducing labour productivity (Parsons, 2014). It is well known that physical work creates heat inside the body and that this affects occupational health performance when combined with excessive workplace heat (Parsons, 2014); the physiological mechanisms have been known for more than 100 years. A steady core body temperature close to 37ºC is essential for health and human performance. In addition, copious sweating from trying to maintain 37ºC during high heat exposure, while working, creates a risk of dehydration (Parsons, 2014). Excessive body temperature and/or dehydration results in slower work, more mistakes while working, increased risk of accidental injuries, together with clinical health effects such as heat exhaustion, heat stroke, and even death (Bouchama and Knochel, 2002; MMWR, 2008; Schulte and Chun, 2009). When heat exposed workers slow down, their hourly work output and productivity goes down (Kjellstrom et al., 2009a), whether the worker is in paid work in a range of industries, in traditional subsistence agriculture, or in other daily life activities. Daily family activities, such as caring for children or the elderly, are also affected by heat (Parsons, 2014)."

The climate change challenges to workplace heat situations

The journal paper (Kjellstrom et al., 2017) also states: "The latest IPCC assessment of human health impacts of climate change (Smith et al., 2014) has highlighted that climate change exacerbates workplace heat and its consequential effects on health and productivity. Our maps to date have shown the potential threats to productivity in selected regions (Hyatt et al., 2010; Kjellstrom et al., 2013). For many middle and lower income countries, more than half of the work force is currently exposed to this type of hazard (Kjellstrom et al., 2009b). Industry-focused analysis exists, explaining, for example, how hot climate conditions reduces worker productivity in gold mines (Wyndham, 1969), in rice farming (Sahu et al., 2013) and in call centres (Niemelä et al. 2002). Furthermore, military operations in regions with thermal extremes are guided by the latest knowledge of this field, such as the United States defence force bulletins (USDAAF 2003).

From the perspective of climate change, the most predictable outcome (with the highest confidence level) is an increase of local temperature levels in most of the world (Collins et al., 2013). Consequently predictions of the impacts of changing thermal conditions in the workplace are likely to be more reliable than, for example, estimates of changing storm patterns, rainfall regimes, wind and related consequences of climate change."

Observations at initial visit to the garment factory in May, 2016

A visit to the factory took place on 3 May, 2016. Ms Sophany from H&M and Tord Kjellstrom were welcomed by local managers and we walked around all the facilities. The factory has approximately 5,000 workers and 90% of the production is purchased by H&M. The aim of this visit was to observe the workrooms and their cooling systems, as well as to discuss issues concerning heat and productivity with staff.

The factory has "air washer" cooling systems in all production areas (except the material storage room), which has a row of strong fans sucking air out of the production room with the air inlet being a steel webbing on which water is slowly passing down. Much of the water on the steel webbing evaporates (unless the outdoor air is very humid) and this cools the inflowing air which then passes the work stations providing cooling for the workers. The system was installed when the buildings were constructed and provides some cooling of the workplace air. Inside each production area there were several thermometers with humidity sensors. On each "area thermometer" the "excessive" levels were indicated with red colour.

According to factory staff the most important feature of this ventilation system is the air flow (wind) inside the production room, as this feels comfortable for the workers. I could observe (during Kjellstrom visit) that many of the workers chose to wear cardigans on top of their shirts, which indicates that they feel more comfortable with double layer clothing. Almost all of the work involves cutting, sewing and inspecting garments, which does not require special work clothing and the physical work intensity is not very high (possibly at a metabolic rate of 200-300W, but this will vary). The workers leave the building during the lunch hour 11am to noon, and are then exposed to the external heat, which may also influence choice of clothing. In the company's experience, the workers still feel comfortable at 28^oC – 31^oC.

In order to get some baseline data on workplace heat exposures it was agreed to put a temperature/humidity datalogger in the shade outside the factory entrance as well as inside a ground floor production area with several hundred workers in it. Five dataloggers were placed indoors: two at the side of the room with the long row of extraction fans, two in the centre of the room and one on the side of the room close to the "air washers". Each datalogger recorded temperature, relative humidity and dew point (absolute humidity) every 5 minutes, and the results were downloaded into our heat data analysis software that produces estimates of the WBGT workplace heat stress index (Wet Bulb Globe Temperature) (assuming air movement at 1 m/s and no heat radiation). The recordings were started at 11 am and stopped at 1.35 pm. The cooling system fans were stopped during the lunch hour 11 - 12, so our calculations would show any effect of this on the workplace heat.

I had received monthly productivity data for 2015 before I came for the visit and made some preliminary analysis with airport weather station data to estimate heat levels each day. I also received after the visit a data file with all the "area thermometer" readings in 2015.

This report focuses on the limited data collected and a more detailed report on heat situation at this factory and in Phnom Penh could be of great importance for the H&M strategy on climate change adaptation and mitigation. More specific proposals for investigations and actions can then also be made.

Table 1. Results of analysis with dataloggers on 3 May. Sewing building C.

Locations of Kjellstrom dataloggers

Outside	In the shade close to the main entrance of the office building
Inside 1	Ground floor, sewing room; Close to main door on air extraction side
Inside 2	Ground floor, sewing room; Further into the room close to extraction fans
Inside 3	Ground floor, sewing room; Central point 1
Inside 4	Ground floor, sewing room; Central point 2
Inside 5	Ground floor, sewing room; Close to air washer air inlet wall

Results of recordings with these dataloggers

	Outside in shade			Inside 1	Inside 2	Inside 3	Inside 4	Inside 5
Time	Temp(°C)	RelHum(%)	WBGT(°C)	WBGT	[Temp] WBGT	WBGT	WBGT	WBGT
11.20 - 12.00	37.2	49.7	31.0	28.7	[40.0] 30.3	28.7	28.0	27.1
12.05 - 13.35	37.5	49.6	31.2	29.7	[40.2] 30.4	29.3	28.3	27.3

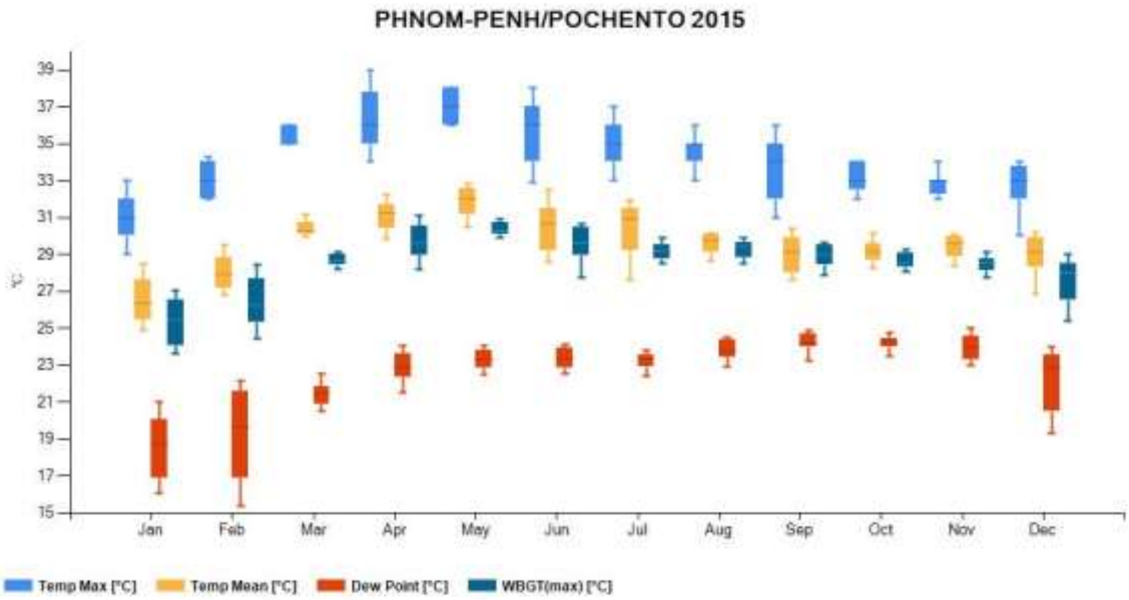
Observing the "area thermometers" and humidity meters inside the different parts of this building, at this hottest part of the day these thermometers usually showed between 32 and 35 ºC and the relative humidity was appr. 50-60%. These results were a bit lower than the datalogger results, where the highest 1.5 hour recording average was 40.2 ºC (see table 1). The highest indoor "area thermometer" temperature measured in this building between 13.00 and 13.25 was 36.5 ºC.

I was kindly provided with a datafile with weekly "area thermometer" temperature and relative humidity data for the period January to November 2015. In January to March these weekly average temperatures were generally between 27 and 30 ºC and the relative humidity 45 - 55 %. (The data on temperature were also labelled as %, but this was surely a misprint). From April to September the weekly average temperatures were in the range 30 to 32 ºC, and after that the data were listed as 30 ºC for each week, which is also likely to be a misprint or lack of data. The relative humidity continued at similar levels as in the first three months.

Based on the weekly data the WBGT during the hottest month goes up to appr. 26-27 ºC, which is at levels that may affect productivity of workers. My measurements during the hottest month and the hottest part of the day (Table 1), indicate indoor WBGT levels after lunch in the range 27 to 30 ºC, while outdoors the WBGT level was 31 ºC (Table 1). These WBGT levels are very likely to affect not only productivity, but also the health of workers, unless they can take frequent rest periods. "Self-pacing" is often mentioned as a preventive policy, but it slows work down (Parsons, 2014).

The weather station data at Phnom Penh airport for 2015 (monthly values) are shown in Figure 1, and in April and May mean temperature values go up to 31 ºC, and the maximum (afternoon) outdoor values go to 35 - 38 ºC, similar to what I measured. The outdoor maximum temperature was on average appr. 37 ºC in April and May of 2015 (Figure 1). The corresponding WBGT levels were 28 - 31 ºC (Figure 1), which matches the values we measured (Table 1).

Figure 1. Weather station data from Hothaps-Soft database.

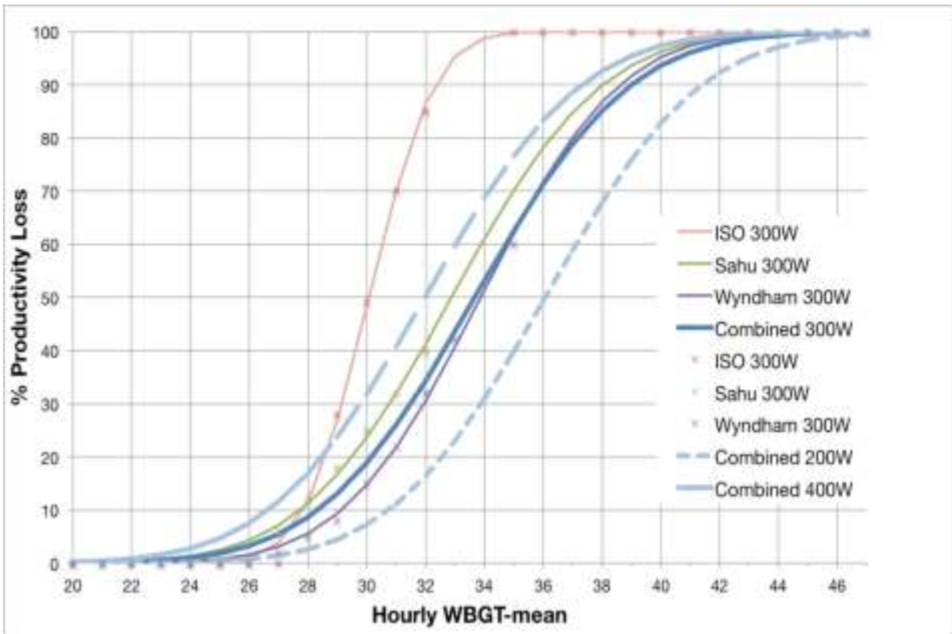


Heat exposure, productivity and comfort

A key question is to what extent the current air washer cooling system provides enough cooling to achieve optimum productivity, comfort and health protection for the workers. In the experience of factory management, workers would still feel comfortable at a temperature level of 28 – 31^{0}C. As was discussed during the visit, it may be very valuable to get more detailed data and to compare daily and hourly heat levels with productivity data from the same time periods (and for periods without other factors of the production process that substantially affect productivity). The bonus system for achievement of daily production goals provides an opportunity to make a quantitative comparison of heat exposure and productivity level. A study of the heat-productivity relationship at this factory would be of local importance, as it may guide opportunities for improved cooling devices and health protection actions. In addition, as there are very few published studies (in any type of production) of this heat-productivity relationship in real working situations it will have global importance in producing improved estimates of the impacts over time. Studies at the factory can be a foundation for further strategy development in relation to climate change mitigation and adaptation.

An analysis from the only two detailed studies available of the heat-productivity relationship is shown in Figure 2. This is based on studies of gold mine workers in South Africa (Wyndham, 1969) and farm workers in India (Sahu et al., 2013), who were carrying out their work in "self-pacing" situations. Nothing similar for factory workers has been published, but one economics study from India indicates the value of air washers over having no cooling at all. The blue curve in the middle of Figure 2 represents work at 300W and the dotted curve below is estimated for 200W (similar to work at the factory). The red curve shows the international standards recommendation for 300W work; beyond an hourly mean WBGT at 34 ºC no work at all is the recommendation. For 200W reduced labour productivity starts at 26 ºC and gets worse for every degree increase of heat. At 28 ºC the loss is appr. 3%. At 30 ºC appr. 7%, etc. However, the data come from two studies, and it may well be that the work carried out at this factory is more affected by heat, or maybe less affected. New studies can help the understanding of what may need to get done. In more intensive work activities the loss of productivity would be greater. Figure 2 shows that enforcing the current international standard would create more lost work time than what is recorded in studies of "self-pacing" workers.

Figure 2. Productivity loss (%) (y-axis) in relation to hourly WBGT heat stress level (ºC, x-axis) as a result of two detailed epidemiological studies of workers in real work situations.



Aims and study approaches

The study aimed at measuring the relationship between hourly or daily heat levels in selected parts of the garment factory and the hourly or daily productivity in the same areas. It can be considered a "pilot study" to test measurements and analysis methods, rather than a full study which would require longer study periods and selection of work days when productivity is not substantially affected by other factors than the heat. A more global aim was to encourage H&M corporation to do more studies of this type and to test the effect on worker productivity, comfort and health of different cooling approaches, and to analyse the impacts of climate change on the workplace heat problems.

Methods

Heat recordings

Lascar dataloggers (model EL-USB-2-LCD+) that recorded temperature and humidity at regular intervals were used to simultaneously measure heat levels inside different locations in the garment factory in Phnom Penh during periods starting in June, August and November 2016. These data were recorded as half-hour values, from which the heat stress index WBGT (Wet Bulb Globe Temperature) was calculated. This index combines temperature and humidity values into a number that represents the physiological impact of the heat level on work capacity and health. The results were summarized into four different sets of WBGT values: a) the daily maximum, b) the values at noon, c) the four-hour average 12.00 to 16.00, and d) the 10-hour average 07.00 to 17.00.

Productivity recordings

Daily productivity data was provided for different departments inside the factory. The term used was "efficiency" (in percent) and it involved input data on the number of workers involved and the product output, but an exact description of the calculation of "efficiency" was not included. The tables we got include "total operators" (e.g. in a department with sewing operators or ironing operators) and "working hours", and apparently the "efficiency" is the ratio between the actual production output and the maximum possible output.

Location of heat and productivity measurements

The three periods of heat measurements are shown in Tables 2 to 4 (starting in June, August and November). In the first period (Table 2) 9 departments were monitored with dataloggers in the centre of the department rooms. In the second period, three locations inside each of three departments were monitored (Table 3). In the third period the same three locations as in the second period were monitored with dataloggers (Table 4). A data logger was installed at the same location outside the department close to the main entrance of the office building (outdoors in full shade) during three monitoring period of June, August and November.

The preliminary measurements in early May was commented upon earlier.

Table 2. Measurements 10 June to 4 July

Building	Floor	Department	Location	Productivity data available	Efficiency, range %
Outside		Main entrance of the office building	Outdoors		
A	2	Ironing/Pressing	Middle	Yes	54 - 92
A	2	Packaging	Middle	Yes	6 - 84
A	2	Checking	Middle	Yes	31 - 100
B	2	Ironing/Pressing	Middle	Yes	17 - 94
B	2	Packaging	Middle	No	
B	3	Cutting	Middle	Yes	0 almost all days
B	3	Sewing (A in list)		Yes	67 - 88
C	Ground	Ironing/Pressing	Middle	Yes	26 - 91
C	Ground	Sewing	Middle	Yes	63 - 82
C	Ground	Cutting	Middle	Yes	17- 96

Table 3. Measurements 20 August to 3 September (a few questions remain)

Building	Floor	Department	Location, Distance to cooling (m)	Productivity data available	Efficiency, range %
Outside		Main entrance of the office building	Outdoors		
A	2	Ironing/Pressing	Inlet, 5		

A	2	Ironing/Pressing	Middle, 25	Yes	28 - 81
A	2	Ironing/Pressing	Outlet, 46		
B	3	Sewing	Inlet, 4		
B	3	Sewing	Middle, 54	Yes	34 - 52
B	3	Cutting (same as Sewing)	Outlet, 92	Yes	(4 - 81 ???)
C	Ground	Ironing/Pressing	Inlet, 7		
C	Ground	Ironing/Pressing	Middle, 35	Yes	28 - 81
C	Ground	Sewing (same as Ironing)	Outlet, 70	Yes	(13 - 68, ???)

Table 4. Measurements 19 November to 3 December

Building	Floor	Department	Location, Distance to cooling (m)	Productivity data available	Efficiency, range %
Outside		Main entrance of the office building	Outdoors		
A	2	Ironing/Pressing	Inlet, 5		
A	2	Ironing/Pressing	Middle, 25	Yes	11 - 65 (low, no supply of materials)
A	2	Ironing/Pressing	Outlet, 46		
B	3	Sewing	Inlet, 4		
B	3	Sewing	Middle, 54	Yes	25 - 49 (low, various reasons)
B	3	Cutting	Outlet, 92	Yes	1 - 22 (low, materials delayed)
C	Ground	Ironing/Pressing	Inlet, 7		
C	Ground	Ironing/Pressing	Middle, 35	Yes	14 - 36 (low, poor supply of materials)
C	Ground	Sewing	Outlet, 70	Yes	35 - 59 (low, various reasons)

The three tables indicate the lack of some data as well as the availability and validity of productivity data. The low productivity in many departments was only commented upon in the third period (Table 4) and these non-environment reasons for low productivity makes any analysis of heat impacts impossible. For most departments monitored in June (Table 2) the efficiency percentages went up to very high values during certain days, so we assumed that these data could be used for heat impact analysis.

Results and comments

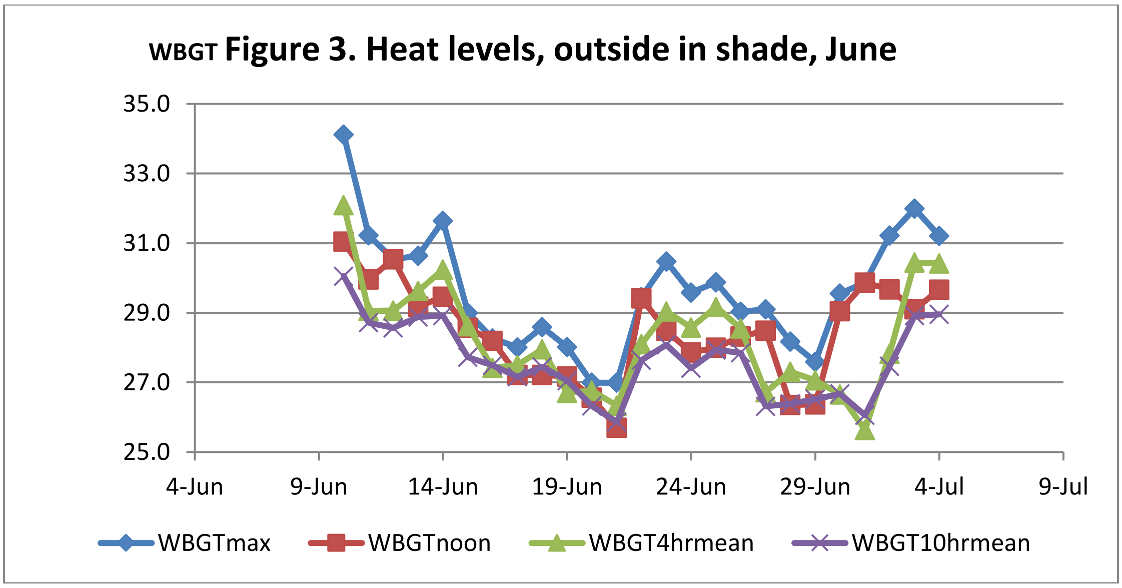
As mentioned above, we present the heat monitoring data in the form of WBGT values:

WBGTmax = a) the daily maximum,
WBGTnoon = b) the values at noon,
WBGT4hr = c) the four-hour average 12.00 to 15.59, and
WBGT10hr = d) the 10-hour average 07.00 to 16.59.

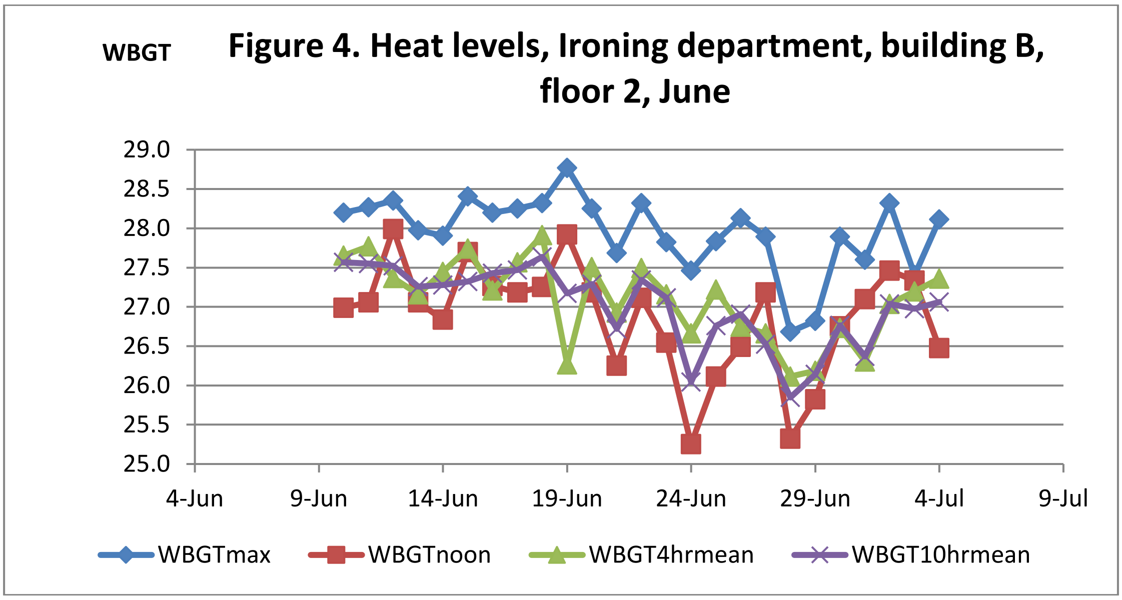
Hourly WBGT higher than 30 (when temperature is above 36°C and relative humidity, RH, is 50% or higher, which was common in June outside the factory at noon) are levels at which people working in moderate physical labour are slowed down because they cannot keep the energy going fully for the whole hour. A WBGT at 26 (Temp at 32°C, RH at 50%) affects people in heavy physical labour and may affect the productivity of the more sensitive people in even moderate or light work and other daily activities. The available information is incomplete, so 26 could be considered a "warning level". The temperatures outside the factory at noon and early afternoon in June varied between 35 and 40°C, and the relative humidity varied between 45 and 55% (as shown in the original datalogger files). The hottest period was the first period (June) and the productivity data made most sense during that period, so we will describe the results from June in most detail.

Heat levels

The four heat stress index (WBGT) variables in the shade outside the factory varied from day to day as shown in Figure 3. The 10-hour mean of WBGT was in the range 26 to 30, so the full day will be affected by excessive heat for many people working outdoors in the shade. The afternoon levels (WBGT4hourmean) are often at one point higher.



The daily variation of the four heat stress variables inside the factory is exemplified by the Ironing department in building B (Figure 4). The WBGT max is generally between 27.5 and 28.5, and the 4-hour afternoon means between 26 and 27.5. The levels are lower than outdoors (logical as the air washer system cools the air) and not so high that major impacts on work would be expected. However, the levels are close to levels of concern and analysis of the potential impacts on the workers' productivity and health is of importance.



The average levels of the recordings outside the factory are always higher than in the nine different departments studied in June (Table 5). The difference is generally 1-2 steps on the WBGT scale and all the 4hr mean (afternoon) values were higher than 26, the first threshold of concern. The C building has the highest WBGT max values, but the 10-hour mean values are similar in all departments and the three buildings.

Table 5. Average values of WBGT heat stress index in the June measurements.

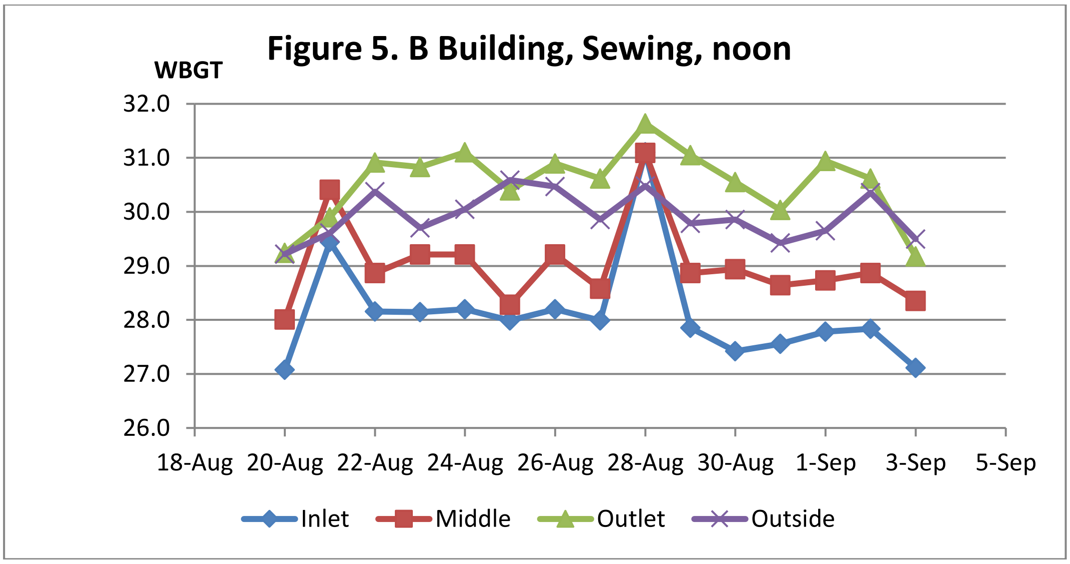
	Floor	WBGTmax	WBGTnoon	WBGT4hrmean	WBGT10hrmean
Outside		**29.6**	**28.5**	**28.3**	**27.6**
A Ironing	2	28.0	26.9	27.1	27.0
A Packaging	2	27.2	26.6	26.4	26.4
A Checking	2	27.7	27.0	26.9	26.8
B Ironing	2	28.7	27.6	27.8	27.7
B Packaging	2	27.7	27.1	26.7	26.7
B Cutting	3	29.2	28.2	27.7	27.5
C Ironing	1	28.7	27.6	27.2	27.1
C Sewing	1	28.8	28.3	28.0	27.6
C Cutting	1	28.7	27.9	27.7	27.4

In the August measurements (Table 6) the outside levels were slightly lower, but the indoor levels were often higher. This may reflect the different impacts of the cooling system during rainy periods (more common in August) vs. drier periods (includes June and November) and would merit further analysis. The air washer cooling system operates during working hours every month of the year. The Inlet values are generally the lowest and the Outlet values the highest, which makes sense in terms of air cooled at the Inlet, but in the A building there are no differences (Table 6). It is interesting to note that both in June and August (the hottest months are actually April and May) the hottest WBGTmax is found at the top floor, number 3. Heat may be introduced via the roof. (this could possibly be reduced by special roof surface treatment or cover; for example see this website:). As shown in Figure 1, May has the highest monthly average of WBGTmax (afternoon values in the shade) and April and June are close. However, it is noted in Figure 1 that the whole year is relatively hot with WBGTmax above 25 degr C in every month.

Table 6. Average WBGT values in the August measurements

	Floor	WBGTmax	WBGTnoon	WBGT4hrmean	WBGT10hrmean
Outside		**28.8**	**28.1**	**27.6**	**27.0**
A Inlet, Ironing	2	27.1	25.7	26.5	26.3
A Middle	2	27.6	25.7	26.7	26.5
A Outlet	2	28.2	27.4	27.0	26.9
B Inlet, Sewing	3	29.0	28.1	28.0	27.5
B Middle	3	29.9	29.0	28.8	28.3
B Outlet	3	30.9	30.5	29.2	28.4
C Inlet, Ironing	1	29.2	28.9	28.1	27.7
C Middle	1	29.5	29.3	28.5	28.0
C Outlet	1	29.9	29.2	29.3	28.6

An example of the daily variation of Inlet, Middle and Outlet values for the B building Sewing department is shown in Figure 5. Inlet at noon is always lower than outside, but at the Outlet the levels are higher than outside. Further analysis of the internal variation of heat levels can provide useful data on the situation and how to change it.



In order to make valid comparisons between measured heat levels and productivity, we need to clarify some of the data issues above, and to add information on the wind speed inside the rooms and alternative reasons for reduced productivity.

Comparison of three measurement periods

As shown in Table 7 there was very little difference in the intra-department heat levels during the three measurement periods. This indicates that any effects of heat on productivity may in fact be quite similar during long parts of the year, and our intention of comparing a "hot period" with a "cool period" cannot be completed. The best way of assessing an improvement of productivity at cooler temperatures would be to test the impact of local effective cooling in one work area. A different type of cooling system can reduce the WBGT values well below the current values (see Discussion).

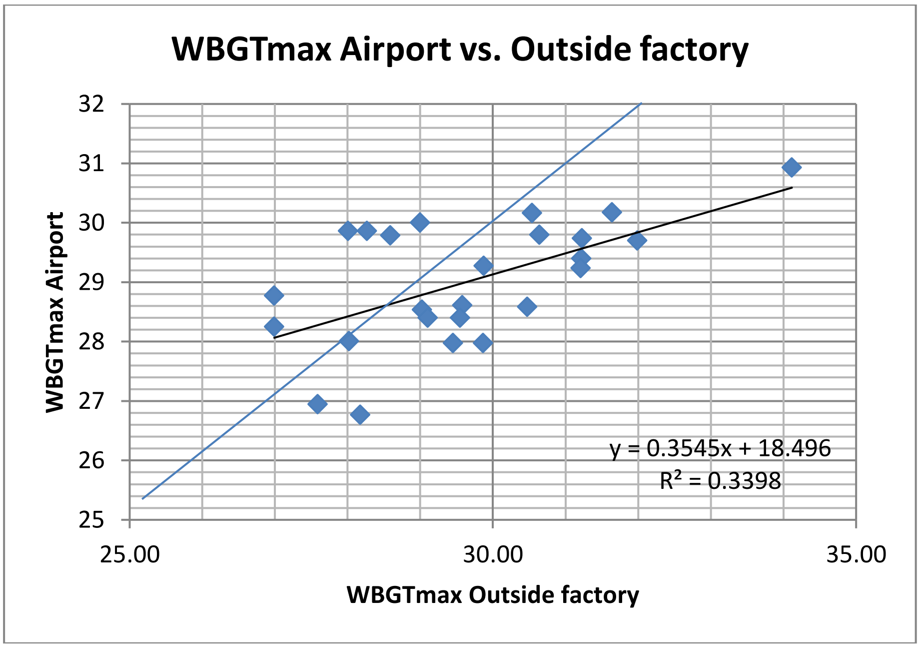
Table 7. Indoor 4-hour WBGT levels in three periods; three departments

Dept	June-July	August	November
A Ironing middle	27.1	27.0	27.6
B Sewing middle	27.7 (cutting dept)	28.8	28.0
C Ironing middle	27.2	28.5	27.7

Comparison of outdoor heat at factory with airport data

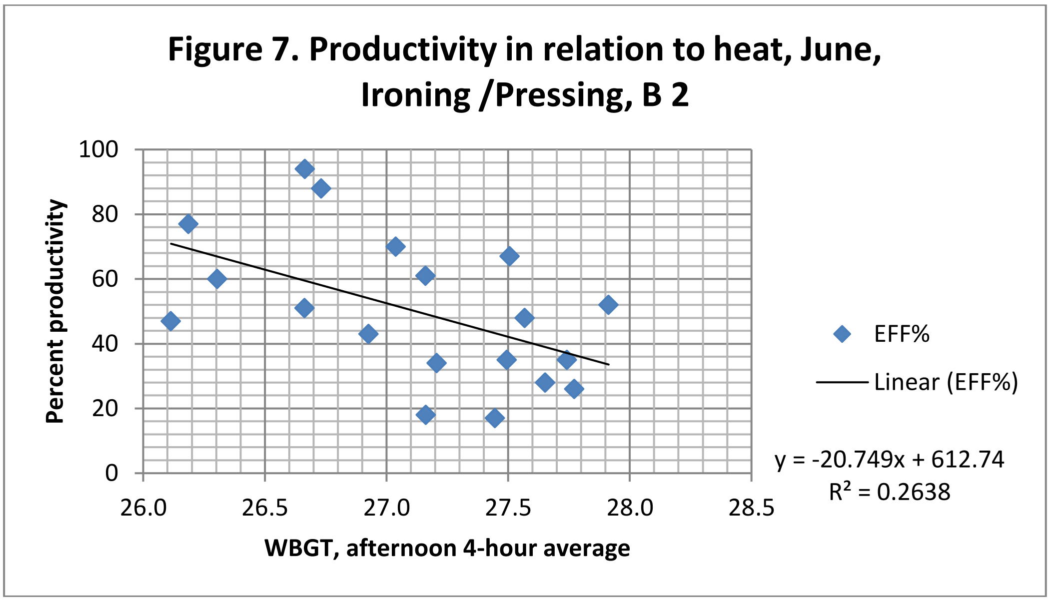
Figure 6 shows the daily WBGTmax data calculated from the outside measurements at the factory and from the Phnom Penh airport data for the same days in the first measurement period. The fitted trend line indicates that WBGT levels measured just outside the factory increases to higher levels than WBGT at the airport as the airport levels increase. This could be a sign of the Urban Heat Island effect (https://www.epa.gov/heat-islands/heat-island-impacts), which makes urban areas hotter than surrounding rural areas. There could also be variations of the difference between airport and factory related to wind speed and wind direction, but this would require further analysis. In any case, when the airport data (or the weather forecast) indicates high heat levels, it may be even hotter at the factory, as Figure 6 shows.

Figure 6. WBGTmax (afternoon values) at the factory (x) and Phnom Penh airport (y)
(dotted line = equality line; continuous line = fitted regression line, see equation)

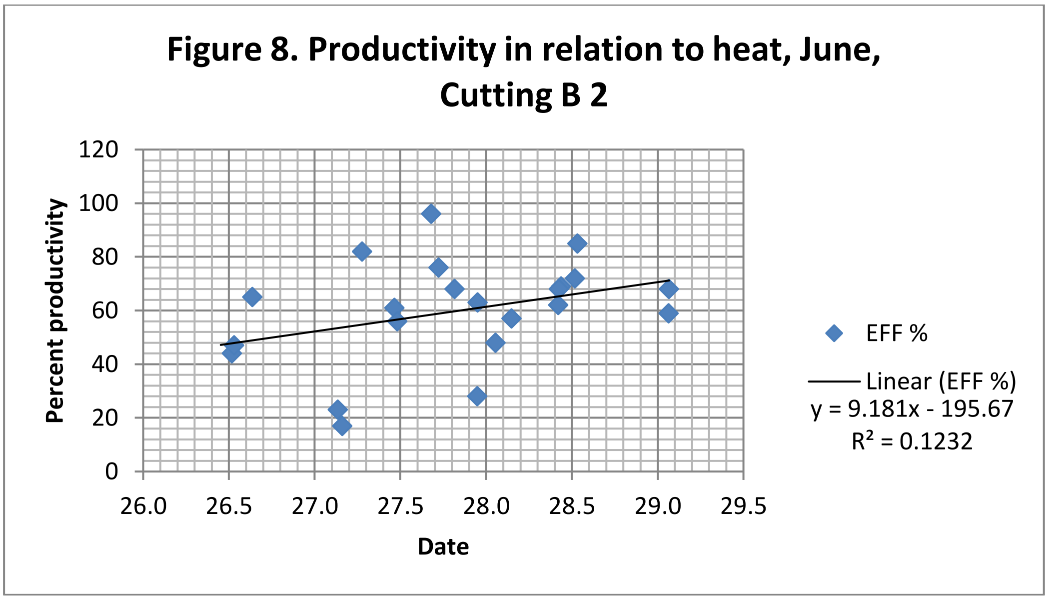


Relationships between indoor heat levels and productivity

Because of the other factors influencing productivity recordings in August and November (Tables 3 and 4) we here show only examples of analysis for the June period. Figure 7, 8 and 9 show three comparisons between afternoon heat levels and daily productivity. There is considerable scatter in the data (r^2 = 0.26, 0.12 and 0.08 respectively), but a clear downward trend for productivity in the Ironing department (Figure 7). This may be explained by such work being more physically demanding than other jobs. The downward trend of productivity for hotter days was statistically significant (see Table 8).



The scatter in Figures 8 and 9 was greater, and the trends were flat (further recording and analysis of productivity data is needed). Comparisons with a cooler period would be of importance, but as shown in Table 7 the differences of indoor heat between the periods are small. The trends in Figures 8 and 9 were not statistically significant. Note the narrow range of heat levels (WBGT scale = 2) in these data.



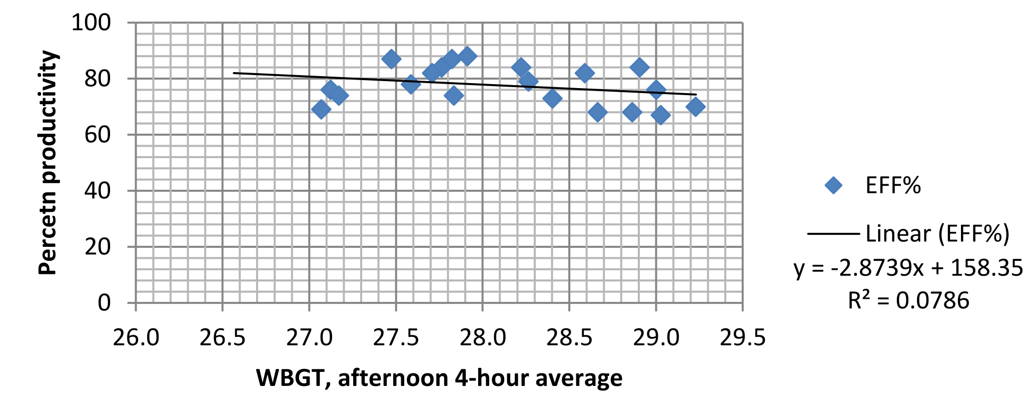


Figure 9. Productivity in relation to heat, June, Sewing C 2

For all the data available from the June monitoring we have calculated the relationships between heat level (WBGT 4-hour average) and daily productivity (EFF%) (Table 8). The three departments coloured yellow in the Table all show statistically significant (p values < 0.01) reductions of daily productivity when the afternoon average heat levels increased. The ranges of the WBGT heat levels are quite narrow (usually only 2 ºC) so we need to find ways of extending the range to cooler days at one end, and to hotter days at the other end in order to produce more definite conclusions.

Table 8. Linear regression and statistical analysis of results for days in June.

Heat data		**Productivity data**		**Equation**	**per degree**		**95% range**		**WBGT**	**Productivity at WBGT**	
Department		X	R2	at WBGT=0	Slope	P-value	min	max	range	26	27
Pressing/Ironing	A2	Yes 2	0.078	241	-6.2	0.219	-16.3	4.0	26.1-27.9	80	74
Packing	A2	Yes 2	0.52	988	-36	0.000	-52.3	-19.2	25.5-27.1	52	16
Checking	A2	Yes 2	0.36	836	-28	0.006	-47.3	-9.5	25.8-27.7	100	80
Pressing/Ironing	B2	Yes 1	0.26	613	-21	0.024	-38.5	-3.0	26.1-27.9	67	46
Packing	B2	Yes 2	Not enough data								
Cutting	B3	Yes 1	0.12	-196	9.2	0.109	-2.2	20.6	26.5-29.1	43	52
Pressing/Ironing	C1	Yes 1	0.085	311	-9.5	0.199	-24.5	5.4	26.2-28.2	64	55
Sewing	C1	Yes 1	0.078	158	-2.9	0.231	-7.7	2.0	27.0-29.2	83	80
Cutting	C1	Yes 2	0.023	-75	4.8	0.506	-10.1	19.8	26.3-28.7	50	55

X = which productivity data files; 1 = first batch, 2 = second batch

Discussion

This pilot study involved some difficulties in collecting systematic heat monitoring data for certain periods, but the results indicate that there are very small differences in the indoor heat exposure levels for the three data collection periods. In addition, the most relevant productivity data were not always available, as other factors than heat exposure apparently had great impacts on the actual productivity. A more precise comparison can be arranged by ensuring that measurements of heat and productivity are carried out during specific hot days (when indoor WBGT in the afternoon reaches above 29ºC) and specific cooler days (when indoor WBGT is below 26ºC) when other factors affecting productivity are not present. This can be arranged by the factory management to further document the problem.

In any case, the datalogger recordings of heat levels inside the different departments are showing levels that are close to or higher than the recommended maximum levels in international and national guidelines. For instance, the United States Threshold Limit Values for WBGT in moderate intensity work (ACGIH, 2011) are 28 or 25ºC, depending on the workers level of acclimatization to heat (Table 9). If these hourly heat levels are exceeded, the workers are recommended to take rest during the hour as indicated in the table. These ACGIH exposure limits are intended to protect most workers (90% at least) from heat-related illnesses. The limits are higher than they would have to be for prevention of discomfort. The international standards for maximum workplace heat are very similar (ISO, 1989). This indicates that a reduction of the WBGT levels inside the factory is an important action to take.

Table 9. United States national recommendations for work/rest cycles (work percentage per hour) at different work intensity and heat levels (hourly WBGT) (ACGIH, 2011).

Allocation of Work in a Work/Rest Cycle	Acclimatized Threshold Limit Value(TLV)(WBGT values in °C)				Unacclimatized Threshold Limit Value (WBGT values in °C)			
	Light	Moderate	Heavy	Very Heavy	Light	Moderate	Heavy	Very Heavy
75-100%	31	28	-	-	28	25	-	-
50-75%	31	29	27.5	-	28.5	26	24	-
25-50%	32	30	29	28	29.5	27	25.5	24.5
0-25%	32.5	31.5	30.5	30	30	29	28	27

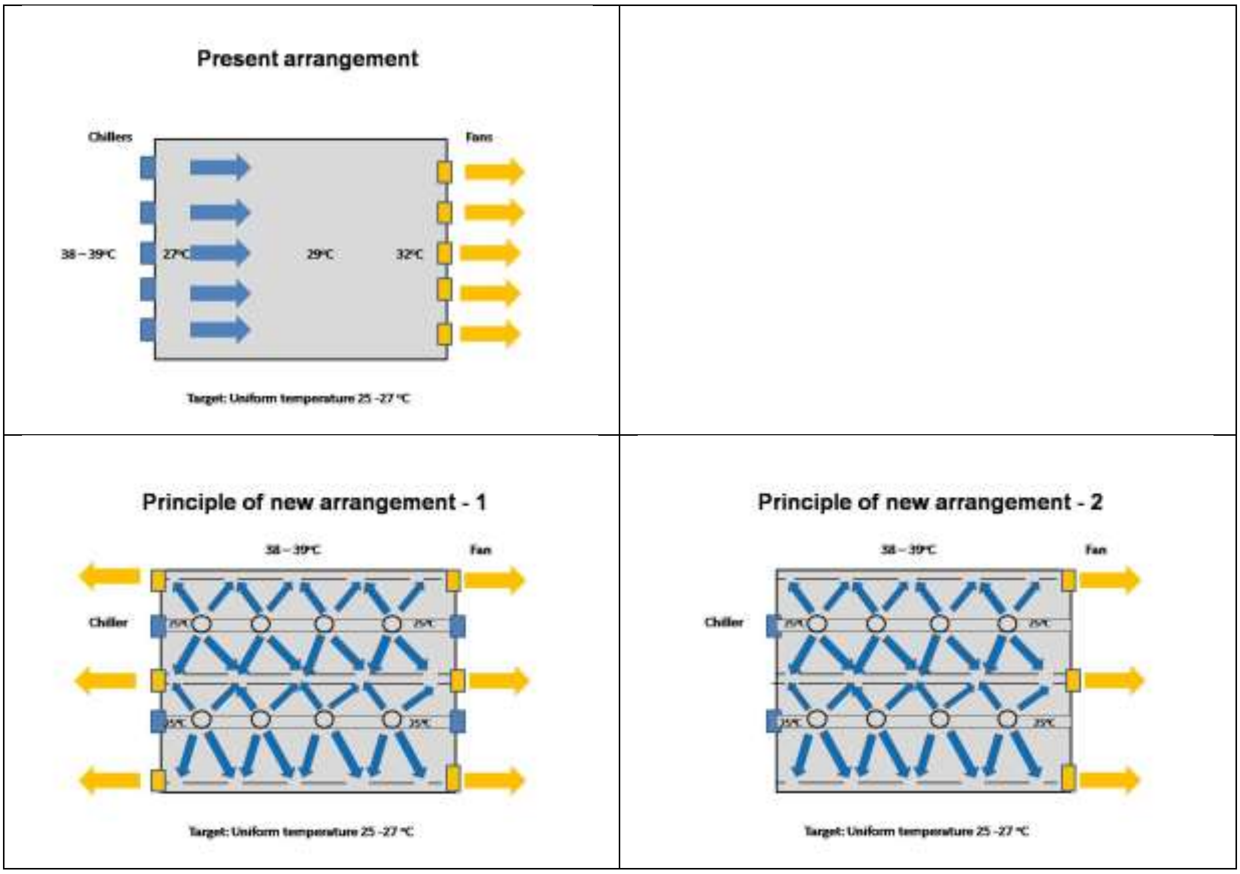
Concerning the relationship between heat exposures and recorded productivity, as indicated above the data collection was not ideal. However, three of the departments had statistically significant decreases of recorded productivity in relation to afternoon heat levels in June, a hot month (Table 8), but we feel that the results are uncertain. If we take the data at face value, the loss of productivity due to heat during hot days is substantial (20% loss with 1 ºC heat increase; see yellow marked data in the last two columns in Table 8), even though the range of heat levels was very narrow (WBGT in the range 25-28 degr C). The other five departments in Table 8 had slopes that were not statistically significant, while three went down and two went up. A new analysis focused on periods of work without other disruptions would help in confirming the local heat effect.

The best way to test improvements in productivity (related to workplace heat) in this type of production would involve installing an improved cooling system in one department and comparing the productivity, comfort and health in this area before and after using the cooling, taking the heat level down to a WBGT around 21-23ºC (which at a relative humidity of 60% means a temperature in the range 25-27ºC). These tests should be carried out when other productivity limiting factors are not likely to influence results.

In November 2016 a Swedish energy analysis expert was visiting Phnom Penh for another energy system consultancy (Professor Björn Kjellström, who happens to be my brother) and he got an opportunity to meet with one of us (Dr Phan) and briefly discuss the issue of cooling systems for the factory. The Swedish expert was not able to visit the factory, but he wrote a short comment after his discussions with Dr Phan.

He wrote: "I am not a specialist in air conditioning and ventilation engineering, but it appears to me that the only reasonably simple solution is to install a duct system at the roof of each department using the present openings in the walls, as illustrated in the attached sketch (Figure 10). I understand that there were five on each side. Exhaust ducts could be placed in the centre and along the walls and air supply ducts on each side of the central exhaust duct. Reversing the arrangement would also be possible but this would require two more chillers, which I assume are more expensive than the exhaust fans. It might also be possible to simplify the arrangement as illustrated in version 2 (Figure 10). The detailed design should be worked out by a ventilation engineer. I would not assume that the cost would be very large. Whether present fans and chillers can be used must also be assessed by a specialist in ventilation. I am sure that there are local companies that can present a solution."

Figure 10. Sketches of potential improvements of air cooling in factory departments



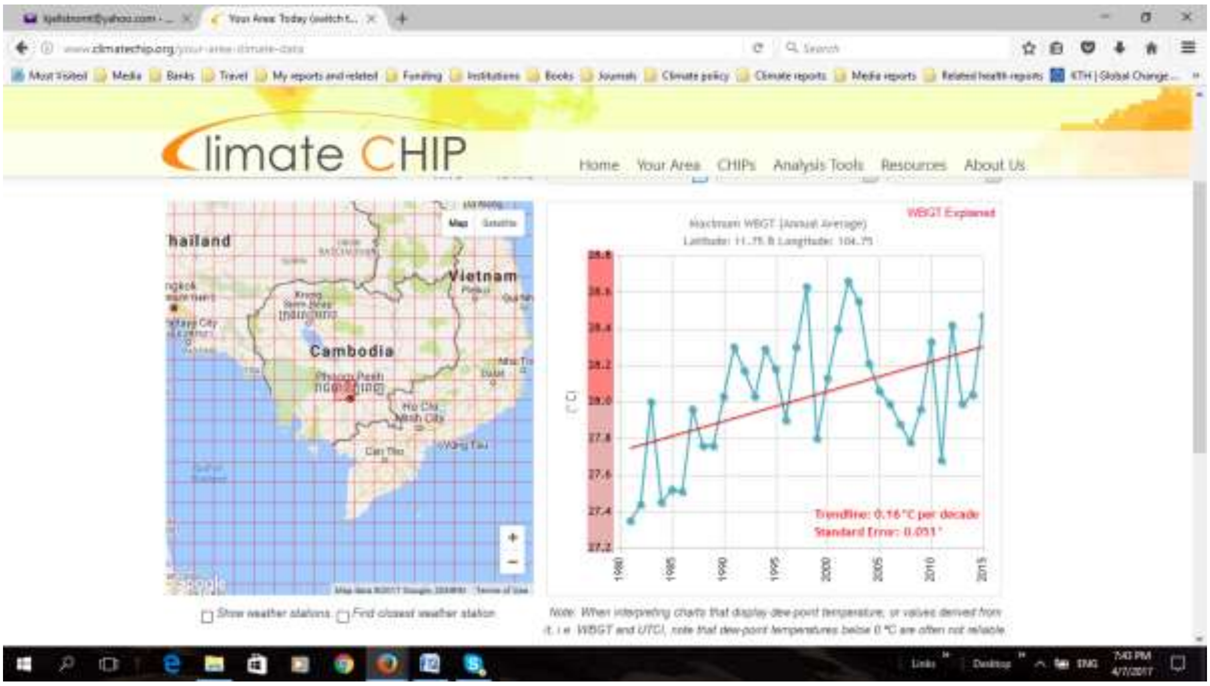
The observation above (Tables 5 and 6) that the top floor appeared to have the highest heat levels may also lead to considerations of protecting the top roof from the strong sunlight heat radiation. There are surface "paint" solutions (see for instance: www.skycool.com.au) to increasing reflectivity of roofs to reduce heat absorption, but another option is to install simple shading covers on top of the roof.

It should be pointed out that several modern cooling systems for air conditioning use solar radiation as an energy source, and in the interest of environmental sustainability (in line with the H&M policies), such systems should be assessed. If such systems improve the productivity and creates economic gains, those gains may well be worth more than the cost of installing and operating the solar driven cooling system. If this can be shown in a follow-up study at this factory, it would be a major finding and with H&M input it could be promoted as a contribution to dealing with climate change.

Heat situation in Phnom Penh, current and future

An important aim of this project was to quantify the impact of workplace heat on productivity, comfort and health of workers in South-East Asian garment industries. The results should be put into the context of the general heat situation in Phnom Penh. The website www.ClimateCHIP.org has data for geographic grid cells (0.5 x 0.5 degrees or appr. 50 x 50 km in Cambodia) showing current heat trends (e.g. Figure 11). The pink to red scale at the side of the WBGT trend line indicates the guideline levels for hourly work percentage. As our data has shown, and Figure 11 confirms, Phnom Penh is already a very hot place for worker productivity challenges.

Figure 11. ClimateCHIP.org website presentation of Cambodia (with grid cell pattern marked) and annual trend 1981-2015 of the WBGTmax levels (afternoon values, annual averages).



The website also shows the estimated future trends in heat levels using five different models approved by the IPCC (Figure 12). The increase of annual WBGT heat levels is between 1.5

and 2.5 ºC (depending on the model), which will create further problems unless workplaces are cooled down with air conditioning systems. This analysis is based on the climate change pathway RCP6.0, which is a reflection of the current global climate change mitigation policies. The variations of monthly average WBGTmax levels is appr. 3 ºC (May the hottest, January the coolest) (Figure 1), so the heat problems vary by month, but the range is small compared to more temperate countries, and Phnom Penh is likely to be substantially affected by the heat problems due to climate change. It should be noted that in a recent report from UNDP (2016) and ILO, Cambodia was one of the most affected countries by workplace heat levels now and in the future with climate change.

Figure 12. Future trend (30-year averages) of annual WBGTmax levels in Phnom Penh (from www.ClimateCHIP.org).

Conclusions

1. The heat levels measured with the dataloggers are often higher than what is recorded by the thermometers in the work areas. This needs to be analyzed further in order to ensure accurate heat exposure estimates in each department. The heat levels in the shade next to the factory are often somewhat higher than the levels recorded at the nearby airport.

2. The heat levels in all departments involved in this study are close to or exceed levels that are known to impact on workers' productivity and comfort. The current air washer cooling system is not sufficient to reduce the heat to levels below maximum recommended levels.

3. The comparison of heat and productivity was not ideal due to other factors influencing productivity on days when heat was monitored. However, in the June period the three Pressing/Ironing departments all had negative slopes in the linear fitted relationships between WBGT 4-hr heat level and daily productivity. The range of heat levels was narrow and only one of these three departments showed statistically significant trends.

4. In the other departments the results were mixed and again further data for a wider heat range will be of great value in assessing the impacts.

5. The three departments with statistically significant downward trends lost 21 - 36% of the EFF% productivity for every degree hotter it was inside the department. Lets' assume that 20% loss per degree is a valid result, and that the monthly variation in the heat levels shown in Figure 7 applies, then the eight hot months may produce 40% lower productivity than the 4 cooler months. Over a whole year, the productivity may be significantly affected (possibly 27% lower than what could be achieved with cooler days all year) by these hot months.

6. The current cooling system brings down the heat levels somewhat at the air entry end and in the middle of the work room, but the levels recorded are still very high in June, August and November. New ways to cool the work environment is worth exploring, and with the interest at H&M in environmentally sustainable industrial solutions, the testing of solar driven air cooling systems would be an interesting and important action. The role of heating of the roof by the sun should also be explored. There are special reflective paints available that could reduce the heat problem at the top floor.

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