Development of a Thermal Perception Index

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ABSTRACT

This study aims to develop an easy and practical simple heat index (SHI) using climatic parameters. This simple heat index was named as a thermal perception index. Most of thermal indices are difficult to calculate or interpret for most normal person. Newly developed thermal perception index (THI) was used only a few variables for input.

1. Introduction

Heat index was originally developed by Dr. Steadman. Its original name was an apparent temperature. US Weather Bureau named as a heat index and used in only summer time. Also, this index can be used in the wintertime like a windchill equivalent index (WCI).

Original calculation for a heat index was complicated, so it was not practically useful for a most people. Therefore, Kwon and Ramsey (1990) developed a thermal perception index. It was validated by an extensive computer simulation and accepted by the original developer, Dr. Steadman.

2. Literature review for developing simplified thermal index

Other studies were also tried to simplify the thermal index with a few climatic parameters.

Quayle was a chief of the applied climatology center and he tried to develop a simple heat index for summer and winter seasons using Steadman's heat index.

Quayle and Doehring (1981) said, "Steadman's work (AT) is the most recent and probably the most comprehensive of all heat stress indices." They indicated that his index is a measure of what hot weather "feels like" to the average person for various temperatures and relative humidities. Because of its versatility, his heat index (apparent temperature) can be adapted to wintertime room temperatures and heating requirements (Quayle and Doehring, 1981).

Kalstein and Valimont (1986) claim that the following equation can simulate a feel-like heat index for a summer season.

$$\text{Heat Index}_{summer} = -2.653 + .994Ta + .368Tdp$$

Where Tdp is a dew point in °C.

Ta is an air temperature in °C.

Kalstein and Valimont (1987) developed to simulate a feel-like heat index for winter season. Their equation is following:

$$\text{Heat Index}_{winter} = 0.453 + 0.991Ta - 1.476V + 0.33Ta*V$$

Where Ta is an air temperature in °C

V is a wind velocity in m/sec

Kalstein and Valimont (1987) noted that only the heat index (apparent temperature) could utilize in both summer and winter seasons. Virtually all other indices are usable only within a single season.

Meisner and Graves (1985) tried to computerize the heat index with a few climatic parameters. But their derived equation was not simple enough to calculate for most people (Kwon, 1990).

Siple (1945) developed the feel-like thermal index for cold windy winter season based on air temperature and wind velocity (Ta and V). His developed windchill index (WCI) equation is following:

$$WCI = (10.45 - V + 10*\sqrt{V})(33 - Ta)$$

Where Ta is an air temperature in °F

V is a wind velocity in m/hr

WCI is a cooling power of the atmosphere in kilogram calories of heat removed per hour per square meter ($kcal/h*m^2$).

Priscoll (1987) developed the equation to simulate WCI in °F with a same component of WCI. He claims that his formula can compute accurately within 1°F when it compares with WCI index. His formula in °F is following:

$$WET_F = 91.4 - (0.474 + 0.303*\sqrt{V} - 0.02V) * (91.4 - Ta) \text{ in °F}$$

where Ta is an air temperature in °F

V is a wind velocity in miles/hr

Kwon and Ramsey (1990) developed the several simplified heat indices (SHI) utilizing a computerized complex heat index algorithm with a computer simulation.

3. Development of a thermal perception index (THI)

Thermal perception index (THI) can be calculated from a few climatic parameters. Equation (1) show a simple one variable prediction, but it cannot predict well for relative humidity changes. Equation (2) uses Pa, which is a vapor pressure with a unit in Kpa.

In wintertime, wind speed is more important than the relative humidity. So equation (3) can be useful for wintertime.

$$SHI = -7.07 + 1.22Ta \ (R^2=.90) \quad (1)$$
$$= -9.18 + 1.14Ta + 3.38Pa \ (R^2=.95) \quad (2)$$
$$= -4.38 + 1.22Ta - 0.27V \ (R^2=.92) \quad (3)$$

Most common people cannot easily understand the concept of a vapor pressure (which is Pa in kPa), so a simple equation was newly developed using air temperature (Ta) and relative humidity (RH). Kwon and Ramsey (1990) developed the winter version of a feel-like thermal heat index. This index uses same components of windchill index (WCI).

$$\text{Heat Index}_{winter} = 3.074 + 0.965Ta - 1.017V + 0.026Ta*V \text{ in } ^\circ C \quad (4)$$

where Ta is an air temperature in °C

V is a wind velocity in m/sec

A computer simulation and a regression analysis made an equation for a modified universal thermal perception index (THI).

$$THI = -3.074 + 0.965Ta - 1.017V + 0.026Ta*V + 0.15RH \ (R^2=.90) \quad (4')$$

Recently Kwon and Ramsey (1998) developed an empirical thermal perception index (KTHI) for an easy computing for most people. The empirical equation was based on the following assumption. Air temperature (Ta) has an 85% of weight and a relative humidity has a 15% of weight for Ta < 30°C. For over 30°C of air temperature, air temperature (Ta) has a 90% of weight and a relative humidity has a 20% of weight. For the wind velocity, $V \le -20$: -V becomes -2V, $-20 < V \le 0$: -V becomes -1.5V, $0 < V \le 20$: -V, $20 < V \le 30$: -V becomes -0.5V, $30 < V$: -V becomes +0.5V in equation 5 and 6.

$$\text{Kwon's THI (KTHI)} = 0.85Ta + 0.15RH - V \ (\text{when } Ta<30) \quad (5)$$
$$\text{Kwon's THI (KTHI)} = 0.9Ta + 0.2RH + 0.5RH \ (\text{when } Ta \ge 30) \quad (6)$$

where Ta is an air temperature in °C.

RH is a relative humidity in %.

V is a wind velocity in m/sec.

For the Kwon's THI, $V \le -20$: -V => -2V, $-20 < V \le 0$: -V => -1.5V,

$0<V\leq20$: $-V$, $20<V\leq30$: $-V \Rightarrow -0.5V$, $30<V$: $-V \Rightarrow +0.5V$

From a computer simulation and a regression analysis, some useful physiological reference information and other derived thermal indices were also developed.

$$HR = 78.0 + 2.0WBGT = 70.5 + 1.52HI \quad (7)$$

$$CET = 2.2WBGT - 37.5 \ (R^2=.61) \ (\text{in } ^\circ C) \quad (8)$$

$$HSI = -1258.6 + 45.3WBGT \ (R^2=.63) \ (\text{no unit}) \quad (9)$$

$$P4SR = -11.42 + 0.45WBGT \ (R^2=.78) \ (\text{in liters}) \quad (10)$$

$$BB = 0.905WBGT - 0.909 \ (R^2=.90) \ (\text{in } ^\circ C) \quad (11)$$

where $WBGT = 0.76TTHI - 3.73$

$= 0.2Ta + 0.1Tg + 0.7Twb$ (for outdoor in °C)

HR is a heart rate in beats/min

CET is a corrected effective temperature in °C

P4SR is a perceived 4-hour sweat rate in g/min

BB is a botsball index in °C

Heat Index can be converted for a widely using a standard WBGT index for a reference.

4. Validation of a heat index

Validation of a simulated heat index was performed for a wide range of environmental conditions. The below two tables show the values for a regression analysis equation and empirical equation (*).

Table 1. Experiment Design of Simulation for Hot Environmental Condition (3X3X3 = 27 combinations)

Ta(C)	24			32			40		
RH(%) / V(m/s)	40	60	80	40	60	80	40	60	80
0.15	26.03 26.25*	29.03 29.25*	32.03 32.25*	33.78 33.28*	36.78 36.28*	39.78 39.28*	41.53 40.08*	44.53 43.08*	47.53 46.08*
1.15	25.63 25.25*	28.63 28.25*	31.63 31.25*	33.59 33.78*	36.59 36.78*	39.59 39.78*	41.55 40.58*	44.55 43.58*	47.55 46.58*
2.15	25.24 24.25*	28.24 27.25*	31.24 30.25*	33.41 34.28*	36.41 37.28*	39.41 40.28*	41.58 41.08*	44.58 44.08*	47.58 47.08*

Note: Ta means an air temperature in °C.
RH means a relative humidity in percent.

V means an air velocity in m/sec.

Table 2. Experiment Design of Simulation for Cold Environment
(5X5 = 25 combinations)

V(m/s)	Ta(°C)				
	-20	-10	0	10	20
5	-30.1 (-27)	-19.1 (-16)	-8.2 (-7.5)	2.8 (3.5)	13.7 (14.5)
10	-37.7 (-37)	-25.5 (-23.5)	-13.2 (-15)	-1.0 (-1.5)	11.3 (12)
15	-45.4 (-47)	-31.9 (-31)	-18.3 (-18)	-4.8 (-6.5)	8.8 (9.5)
20	-53.1 (-57)	-38.3 (-38.5)	-23.4 (-30)	-8.6 (-11.5)	6.3 (7)
25	-60.8 (-67)	-44.7 (-46)	-28.5 (-37.5)	-12.4 (-16.5)	3.8 (4.5)

Note: Ta means an air temperature in °C.
V means an air velocity in m/sec.

Following picture shows that heat index (HI) changes by not only air temperature but also relative humidity.

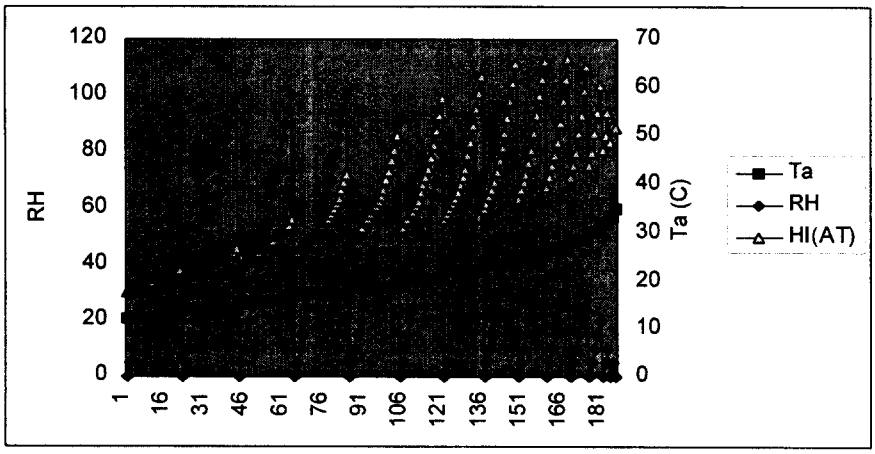

Figure 1. Simplified heat index (SHI) changes
by air temperature (Ta) and relative humidity (RH)

Simplified Heat Index (SHI) = -16.886 + 1.359Ta + 0.189RH - 0.5V

THI = -3.074 + 0.965Ta - 1.017V + 0.026Ta*V + 0.15RH

5. Discussion

Heat index is a useful indicator of how human feels from the thermal environments for summer and winter seasons.

Preliminary analysis of Kwon and Ramsey's Thermal Perception Index (THI) gave a satisfactory result, and showed a fairly good accuracy when comparing with a real data.

For a easy computing, KTHI = 0.85Ta + 0.15RH - V (when Ta<30) or

KTHI = 0.9Ta + 0.2RH + 0.5RH (when Ta≥30) empirical equation can be used without a

sacrificing of an accuracy. Without separating summer and winter indices, a universal thermal index, THI = -3.074 + 0.965Ta - 1.017V + 0.026Ta*V + 0.15RH can be used for an accurate computing.

Furthermore, simplified heat indices are easy to understand and easy to calculate for most normal person.

References

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