Received: 22 October 2021 | Revised: 1 December 2021 | Accepted: 6 January 2022

DOI: 10.1111/1556-4029.14989

JOURNAL OF FORENSIC SCIENCES AAFS

PAPER

General; Pathology/Biology

Fatal pediatric hyperthermia: A forensic review

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Abstract

This paper examines a pediatric hyperthermia homicide in which the decedent was placed into a room with only a diaper on and left unattended overnight. There were no furnishings in the room except for a 1500-W space heater and a stroller. The following morning, emergency personnel were summoned to the residence. A caretaker said the decedent was playing normally 5 min before making the 911 call. The decedent's initial rectal temperature was 42.2°C. Law enforcement asked how long the child had to be exposed to a high temperature in order to induce fatal hyperthermia in an empty bedroom. The scene was reconstructed using the child's residence and the same heater. Environmental data were gathered over a 16-h period. The thermal parameters of the room and environment were analyzed using a lumped-element thermal model. These parameters were then fed into an adapted Gagge's two-node model of human thermal regulation, which provided a time-window of exposure necessary to elicit hyperthermia, which in this case, depending on certain variables, ranged from 45 min to 4 h.

KEYWORDS

basal metabolic rate, core body temperature, environmental mortality, fatal hyperthermia, heat injury, heat stroke death, human thermoregulation, medicolegal death investigation, pediatric homicide, pediatric hyperthermia

Highlights

- Science disproves caregiver reports of a pediatric hyperthermia homicide via forensic physics.
- Scientists recreate a fatal setting to determine the timeframe of heat exposure to the decedent.
- Academics and law enforcement collaborate to uncover the truth of a toddler's untimely death.

1 | INTRODUCTION

Perhaps, the most heart wrenching cases to investigate are those of child death. Unfortunately, there are too many of these types of cases each year. A number of them are accidental or natural whereas others are homicidal, whether through an affliction of some means (abuse) or due to negligence by a caretaker. This case study examines a pediatric homicide due to exposure to extreme indoor environmental conditions consistent with neglect and hyperthermia.

The event occurred during the winter months in the South East United States. Two children, ages 4 years and 14 months old, were placed into a room devoid of any furnishings aside from a 1500-W space heater and a stroller to sleep. Both children were male and naked except for a diaper or underwear. The house they were in was a mobile home in disrepair. Local authorities were alerted to a medical emergency during the mid-morning hours of December. Upon the arrival of emergency personnel, the two children were located in the front yard and unresponsive. Emergency responders began life-saving procedures and quickly transported the children to a local hospital. The older child survived the event. The younger child, 14 months old, succumbed to his injuries. The decedent was described as extremely pale, cyanotic, clammy, hot to the touch, and eyes open in a "relaxed" state and had a recorded rectal/core temperature of 42.2°C at the scene, prior to transportation to the hospital.

Law enforcement reported that an investigator noticed the room the children had slept in was excessively hot. The heater was unplugged already. Officials measured the room temperature approximately 45 min to an hour after arrival to the scene. Four samples of roughly 31.8°C were recorded. The walls and doors were hot to the touch, and investigators said the heat in the room was like walking into a wall. Eventually, the room was tested for carbon monoxide. Using an approved device, firefighters determined the level of CO in the room was 0 ppm.

During the initial stages of the investigation, the caregivers reported to officials that allegedly 5 min before the 911 call, the children were playing normally. One caregiver noticed that one or both of the children demonstrated strange behavior and phoned for an ambulance. During the time it took for emergency responders to arrive on scene, the caregivers reported that the children became unconscious.

Law enforcement suspected hyperthermia due to the excessively hot room. An autopsy of the decedent revealed petechiae along with the epicardium, which is consistent with hyperthermic injury. Hyperthermia is best defined as an elevation of the body's core temperature of >40°C [1,2]. The body's temperature is regulated at 37 ± 0.9°C by way of the preoptic anterior hypothalamus [3,4]. When the body's core temperature exceeds the regulated temperature, significant and potentially fatal changes impact the organs and central nervous system. The question thus became "How long were the children in the heated room to achieve fatal hyperthermia?"

The first author was contacted by local law enforcement and asked to run an experiment at the crime scene to determine how long the room must be heated and how long the children had to be exposed in order to manifest hyperthermia to the degree documented. After securing a search warrant, law enforcement and the first author returned to the residence and began the experiment in the evening hours using the same heater (investigators had placed it into evidence and brought it back). The experiment ran for approximately 16 h. At the start of the experiment, the room temperature registered 20.5°C. At its conclusion, the room measured 41.0°C. Photographs of the recreation, as well as records of what transpired during the experiment, were maintained by the first author and appropriate law enforcement organizations. The room where the incident occurred is best described as an empty bedroom measuring 9′ 4″ wide by 11′ 5″ long and a ceiling height of 7′ 2″. The heater was placed back by law enforcement where they originally found it. At the onset of the investigation, two digital instruments that measured temperature, relative humidity, and heat stress indices were placed in the room where the victims spent the night preceding the heat injury. One sensor, D2-2484988, was placed approximately where the children were reported to have slept (note: there was no furniture in the room aside from the heater and a baby buggy/stroller). It was this sensor that recorded the 41°C reading. The other sensor, D2-2484992, was placed roughly nine feet away at a location against the wall opposite from where the heater was located during the event, further away from where the children slept and further away from the heater than sensor D2-2484988. The experiment commenced at approximately 9:50p (2150). The instruments were programmed to take measurements every 10 min. The first reading of inside the room was at 9:50p (2150) and the final reading was at 1:30p (1330) the next day. At about 10:50p (2250), temperatures in the room rose to a level where the air temperature of the room coincided with the heat stress index temperature (approx. 26°C).

Data were collected from the residence and analyzed to ascertain how long the children were subjected to the heat (Table 1 and Appendix A; see also the inset of Figure 1 for a plot of the data). This question precluded a simple turn to the literature and there was noted a glaring gap in it relating to fatal thermal transfer in pediatric victims of this nature, and presented a question of thermodynamics and energy transfer. Even the literature notes that "Despite the appearance of anecdotal reports, systematic review of the circumstances, pathology, and manner of death in a series of fatal pediatric [hyperthermia] cases are lacking" [5, p. 374].

1.1 | Assumptions and limitations

The reader should not interpret the results as absolute as there may be variance depending upon the limitations expressed. We used the information that was available for us, which included records from emergency personnel, hospital/medical records, autopsy notes, and our own measurements of the room temperature during the crime scene reconstruction.

The room's thermal property parameters within this text are not assumed and are derived from measurements. A major limitation to this case study is the lack of absolute certainty of the events leading up to the time emergency personnel arrived at the scene. One does

TABLE 1 Data collected during the experiment are shown here in 2-h increments

		D2-2484988 (°C)	D2-2484992 (°C)
Start	2150	20.5	20.6
1 hr	2300	28.1	26.8
3 hr	0100	33.8	32.1
5 hr	0300	35.8	34.1
7 hr	0500	36.9	35.3
9 hr	0700	37.8	36.2
11 hr	0900	38.6	37.1
13 hr	1100	39.5	38.0
15 hr	1300	40.6	39.3
End	1330	41.0	39.7

not know for certain if the deceased child was placed into a room that was initially at the outside temperature or near heat saturation. Neither does one know the core or skin temperature of the decedent when placed into the room. Another limitation is that the two-node model adapted in our analysis tends to underestimate core temperatures and over predict skin temperatures [6].

2 | LITERATURE REVIEW

2.1 | Hyperthermia

The majority of instances of fatal pediatric hyperthermia are usually relegated to either conveyance deaths [5,7,8] or as a result of sleeping while wrapped in an electric blanket or heavy clothing [9,10]. Generally, when children are left in vehicles on hot days, in direct sunlight, and with the windows rolled up, the interior temperature swells quickly to a temperature that will trigger a heat stroke, leading to organ shut-down and death [8,11]. Within a home, children who are wrapped in blankets or heavy clothing are susceptible to hyperthermia [4,12] and those who have a heat stroke while in bed are often not discovered until the following morning [5,13]. There appears to be no literature on children suffering hyperthermia who are unclothed in a dwelling overnight.

Hyperthermia is a clinical term that indicates a person experienced a core temperature of >40°C [1,2]. It typically suggests that the patient, if not exercising, had prolonged exposure to elevated environmental temperatures where the patient's body was unable to dissipate heat [14]. This is distinguished from hyperpyrexia and fever due to infection [14]. The human body's core temperature is regulated at 37 ± 0.9°C [3,4]. Hyperthermia impacts the cerebral thermoregulatory system, specifically the preoptic anterior hypothalamus, which regulates the body's temperature [3,4]. Given that children have greater body surface/volume ratios than adults, greater rates of metabolism, and lessened abilities to sweat, they are more prone to hyperthermic fatalities [3,14,15]. In instances where a victim's antemortem temperature reads >40.6°C, medical examiners should classify the cause of death as hyperthermia [16].

The process of generating heat is metabolism. The heat generated by the body and its organs is referred to as the basal metabolic rate (BMR). Other contributions to heat generation can be found in effects of hormones, stimulation of the sympathetic nervous system, or voluntary muscular activity such as exercising. As the heat level in the body surpasses the regulated 37°C, the body must cool. In the case of hyperthermia, the body's sympathetic reaction to environmental temperature changes is to balance heat production and loss. Heat is moved from the core to the skin and from there to the environment [1]. There are four methods by which heat is released to the environment: conduction, convection, radiation, and evaporation [1]. *Conduction* involves direct contact of the body with something that is cooler, such as an ice pack or cold floor. *Convection* involves moving air, where the heat is released to the surrounding environment such as witnessed when cooking with a convection oven. *Evaporation* is perhaps the most common method of heat release. When the environmental temperature exceeds 37°C, (the regulated core body temperature), the most common way for a human body to release heat is through sweating/evaporation [1,4]. Roughly 0.59 kcal (~2400 J) of heat is lost for every gram of sweat that evaporates from the body surface [1], which corresponds to water's latent heat of evaporation/condensation. In instances where heat loss is not sufficient, damage to the body occurs. According to one study that reviewed pediatric hyperthermia patients, aged 52 days old to 2 years, exposure to temperatures in excess of 37°C between 4–7 h in duration resulted in patient body temperatures recorded between 39.9–41.3°C [5].

The most severe aspect of heat-induced injury occurs when the body reaches a temperature exceeding 40.6°C. This derangement is referred to as heat stroke, and it broadly falls into two categories: exertional heat stroke and classical heat stroke [13]. Since exertional heat stroke is associated with physical activity, it is not relevant to this discussion whereas classical heat stroke is. After a person is exposed to temperatures exceeding the core body temperature, and the core temperature rises to a level of destruction, a fatality usually ensues. A common example of classic heat stroke involves infants left in a car during the summer months. Once a body exceeds 41°C in temperature, it is considered to have exceeded the thermal critical maximum to sustain life [4,11]. Cytotoxicity, systemic inflammation, and hemorrhage follows. During autopsy of hyperthermic decedents, generally there are no definitive indicators to point directly to hyperthermia, although findings that support hyperthermia include petechial hemorrhages on the skin, thymus, spleen, visceral pleura, and epicardium [5,13]. For this reason, it is important for the investigator to collect evidence from the scene that may aid in reaching a conclusion of the fatal event. Of great importance is quickly obtaining a temperature reading of the decedent, of which a rectal temperature is preferred, and notations made of the temperature in the area directly where the fatality occurred (if in a conveyance or structure of some form), as well as the outside temperature. Environmental conditions should be recorded (day/night, sunny/cloudy, et al.). If there are any electrical devices in use, those need to be documented and seized by law enforcement for evidence, if necessary. It should be noted whether the appliance(s) was in working order at the time of the event and whether turned on or not.

2.2 | Signs and symptoms of hyperthermia

In cases of fatal hyperthermia, there are common signs and symptoms that present. Symptoms are what the patient experiences and signs are those items that are observed. Symptoms include confusion and/or unconsciousness [4]. Signs may present as restlessness, hot and dry skin, and a core body temperature of 40°C or higher [4]. As a result, the central nervous system (CNS) collapses [4]. CNS collapse is not always predicated by heat cramps or heat exhaustion [4].

Often, the victim will have hot skin that might feel dry to the touch [2,4]. Pupils may be constricted in living patients [4] and the conjunctiva dry in deceased cases [17].

Hyperthermia induces multiple organ failure and death [4]. Those surviving longer than 24 h may exhibit adrenal hemorrhages, acute tubular necrosis, pneumopathic lesions, and liver necrosis [17]. In deceased victims, a postmortem examination should attempt to ascertain raised levels of creatinine kinase (CK) [4]. Thermal injury may be evident through cellular or circulatory changes related to hyperthermia, and these changes cause systemic injury to the heart, kidney, liver, blood, and CNS system [4]. Conjunctival, cutaneous, and intrathoracic petechiae may be evident, with the latter more common [5], as was in this case. Cerebral edema, pulmonary edema, cellular degeneration, and visceral necrosis may be evident also [5]. The cerebral hemispheres and brain stem may demonstrate observable petechial hemorrhages during autopsy [4]. For those surviving <12 h, the only discernable abnormalities during postmortem examination may be intrathoracic petechial hemorrhages on the surface of the organs, namely the heart and lungs [1]. Livor and rigor mortis can set in very quickly [17].

2.3 | Human thermoregulation

The body regulates temperature through a balance where heat gain must equal heat loss [1]. Heat generation inside the human body is measured in terms of Met, or (specific) metabolic rate, where 1 Met = 58.2 W/m^2 or 18.4 btu/(hr·ft^2) [18,19], where the normalization is made with respect to the body surface area. Since some studies noted mean ranges of pediatric Met from 45 to 69 W/m^2 [20–22], we elected to use the traditional Met of 58.2 W/m^2 for this study [23], which is roughly the mean of the aforementioned range. Precise methods of arriving at individual Met exist, but due to the timing of our involvement in this case, circumstances precluded using those methods. Literature suggests that variance in resting (or sleeping) BMR is a result of individual body fatness [22]. Children have greater organ mass relative to the body, which results in a higher metabolic rate [24]. Attempts to normalize individual BMR are largely unsuccessful and an acceptable method to determine it uses the DuBois method, deriving an estimate of body surface area from height and weight [24,25].

In hot environments, heat gain comes from surroundings. Heat loss is a function of heat moving from the inner core to the environmental surroundings by way of the skin [1]. In environments where temperatures exceed skin temperature, all heat loss from the body is done via sweating [1]. When the relative humidity is high, heat loss due to evaporation is severely limited [1]. In an adult, when sweating, the maximum rate of sweat generated is typically about 1 L per hour or less [1]. The higher the humidity, the slower the heat loss process is. At an inner core temperature of 40°C, the main areas of tissue damage are located in the brain, liver, kidneys, muscle, and bone marrow, explained by the body's movement of blood from the core to the skin in an effort to lower the core body temperature [1].

2.4 | Two-node model

The two-node model was designed to predict the mean body temperature (core), mean skin temperature, sweating rate, and shivering rate and tested over 60 years, proving reliability in predicting whole body mean temperatures, as well as sweat production in indoor environments [26]. It is a fairly reliable model for a subject at rest or engaged in easy, low-level exercise [6] and thus became the selected model for this paper. A benefit of this model is its accuracy for predicting skin temperatures for those at rest, of which the error rate is essentially zero [6]. It accounts for physical exertion, thermal environments, metabolic rate, and insulation/clothing by dividing the body into roughly two compartments. Dubbed as cylinders, the innermost cylinder is conceptualized as the body's core of which is encased in a skin cylinder. The boundary between the two cylinders is blood and some tissue, and thus changes in these cylinders can be induced by the flow rate of blood to the skin. This effect is captured in a parameter, alpha, representing the fractional ratio of the skin mass compared to the body mass [6]. A formula to determine this balance exists [27] and was incorporated and analyzed in this study. The adapted two-node model used in the present work ultimately accounts for, and considers, the effective shell thickness (or body mass at the core and skin by way of the fraction of total body mass) [27], body surface area [23], thermal regulation and the effect of thermal feedback signaling [27], skin blood flow [27], heat transfer from core to skin [28], and heat losses to the environment [27].

There are other models, more advanced and specific, that were not selected for use in this study as they required more known parameters than what was available for this occurrence. Thus, this study selected the two-node model based on the known parameters and established reliability.

3 | METHODOLOGY

This case was interpreted using the two-node model of human thermal regulation [6,26,27,29–31]. The body surface area of the children was estimated using the DuBois Equation [23]. The following table, Table 2, represents the victim in this case and for comparison, a typical adult male:

TABLE 2 DuBois estimation of body surface area

Height (m)	Mass (kg)	Body surface area (m^2)	Age
0.7	10	0.42	Victim
1.7	70	1.81	Adult male

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3.1 | Parameters of the room and environment

First responders reported, as part of their investigation, that the temperature of the residence was 23.8°C, except for the room where the death occurred. Reports list the 23.8°C temperature as an approximation; we rounded it to $T_{a0} = 24.0$°C for the room in the simulation (it is also reasonable to assume that the initial temperature of the room is slightly higher than that of the residence due to its improved thermal isolation). On the day the crime scene was reconstructed, the outdoor temperature measured was 20.5°C (initially, on the day of the reconstruction, the power to the residence was shut off, so the interior temperature was the same as the exterior temperature), so there was some variance of the temperatures between the day of the event and the reconstruction although any uncertainty in this regard is minimal and it has no effect on the determination of the thermal parameters of the room.

T_e: Outdoor temperature and for this is set at 23.8°C (initial outdoor temperature as recorded by law enforcement).
T_{a0}: Initial room temperature and it is set to either 24.0°C (assuming that the decedent was placed in a room that was initially at approximately the outdoor temperature) or 38.0°C (assuming that the decedent was placed in the room after it had been fully heated up). With a thermal link of $K_{rm} = 110.0$ W/°C (see below), 38.0°C is the maximum temperature one can reach in the room with a 1500 W heater and an outdoor temperature of 23.8°C.
P: the amount of heat provided by the heater, 1500 W.
RH: relative humidity, which is set at 90.0%.
T_{sk10} and T_{cr10} are the initial skin and body core temperatures, respectively, used in the standard two-node model [29] (Table 3).

There was, at the onset of this study, one glaring question that needed to be answered in order to determine a timeframe of exposure: What was the temperature of the room at the time the children were exposed? Arguably, the answer to this was unknown, and therefore, the modeling based on data gathered during the search-warrant investigation were run twice. One simulation used the baseline temperature recorded during the death investigation where the outdoor temperature was recorded as approximately 24.0°C. The second simulation assumed the room was already at or near thermal saturation and thus the baseline was set at 38.0°C. The search-warrant investigation provided a different starting temperature from what law enforcement records reflected (due to the fact that the search-warrant investigation was conducted on a different day). During the death investigation, the baseline temperature was approximately 24°C whereas the search-warrant investigation was 20.5°C. Thus, we elected to use the death investigation baseline temperature for our simulation. Therefore, T_e represents the death investigation baseline temperature of approximately 24.0°C and T_{a0} represents either 24.0°C (death investigation baseline temperature assumption) or 38.0°C (fully heated room temperature assumption).

Thermal properties of the room (where the fatality occurred) were deduced from data collected by the first author during the crime scene reconstruction experiment. We described the thermal behavior of the room using a lumped-element model with two parameters [32,33], namely, its heat capacity (C_{rm} measured in J/°C) and its thermal link to the environment (K_{rm} measured in W/°C). One important thermal parameter that is relevant to this study is the thermal time constant (τ) which is defined as

$$\tau = \frac{C_{rm}}{K_{rm}}$$

This time constant dictates the characteristic timescale in which the room's temperature can be modified by any physical means. In the inset of Figure 1, we present the temperature evolution as a function of time registered by both thermometers during the crime scene reconstruction.

The temperature increased quickly in the first 3–4 h after the heater was switched on, showing signatures of a system that can be described by a single thermal time constant. The temperature then drifted upwards almost linearly for the next 8–9 h before the heater was turned off. We attribute this slow upward temperature drift to the rise of the outdoor temperature during daytime. In order to obtain the thermal parameters of the room, we select the near-linear portion of the data recorded by thermometer D2-2484992 (which was placed against the wall from where the heater was positioned) between 4:00 a.m. and 12:50 p.m., and fit them with a straight line. This portion of the data involve a temperature increase of 4°C, which is exactly the same as the local outdoor temperature change during the day on which the crime scene reconstruction was conducted [34]. The fitted straight line was then subtracted from the original data to reveal the intrinsic thermal response of the room

TABLE 3 These values represent room and decedent variables

Temperature of the residence	T_e	23.8	°C
Initial room temperature	T_{a0}	24.0 or 38.0	°C
Heat delivered by the heater	P	1500	W
Heat capacity of the room	C_{rm}	550×10^3	J/°C
Thermal link between the room and the environment	K_{rm}	110	W/°C
Relative humidity	RH	90.0	%
Initial skin temperature of decedent	T_{sk10}	34.1	°C
Initial core temperature of decedent	T_{cr10}	36.6	°C

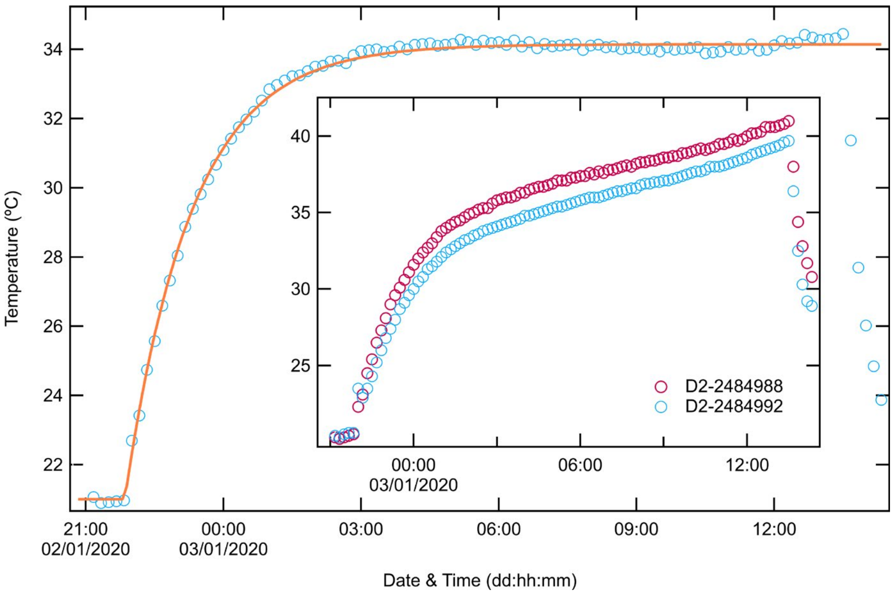

FIGURE 1 Temperature response of the room registered during the crime scene reconstruction experiment after a background due to the local outdoor temperature drift is subtracted. The solid line is a fit to the behavior of a thermal system governed by a single time constant (see text). The inset shows the raw data logged on the two thermometers as a function of time

(see Figure 1). We fit the data in Figure 1 to the following equation, which describes the response of a thermal system governed by a single time constant:

$$T(t) = T_{max} + \left(T_0 - T_{max}\right) \exp\left(-\frac{t}{\tau}\right)$$

in which T_0 is the initial temperature of the room, T_{max} is the maximum temperature, and τ is the thermal time constant. The best fit parameters are $\tau \approx 5000$ s (1 h and 40 min) and $T_{max} - T_0 \approx 13.5^\circ$C. The thermal link of the room can be estimated as

$$K_{rm} = \frac{P}{\Delta T_{max}} = \frac{P}{T_{max} - T_0}$$

with P being the power of the heater (1500 W). Thus, the experimentally obtained C_{rm} and K_{rm} are

$$C_{rm} = 550\,\text{kJ} / ^\circ\text{C}$$

$$K_{rm} = 110\,\text{W} / ^\circ\text{C}$$

These thermal parameters contain an uncertainty in the order of ~20% with its main source coming from systematic uncertainty during curve fitting and subtraction. The thermal parameters are in the same order of magnitude as those used in the literature [35,36].

We want to point out that since the outdoor temperature was 23.8°C on the day of the incident, using this time constant of 5000 s, the heater would have to be on for at least ~4500 s (1 h and 15 min) for the room to reach an average temperature of 31.8°C, as recorded by officials approximately an hour after their arrival at the scene. Although it does not directly correspond to the time it took for hyperthermia to take hold in the decedent, it provides indirect evidence of how long the decedent might have been left in the room.

TABLE 4 The various parameters of the decedent used as part of the two-node model

Total body mass	m	10.0	kg
Alpha parameter for skin mass distribution	alpha	0.05	
Skin mass of decedent	m_{sk}	alpha × m	kg
Core mass of decedent	m_{cr}	(1−alpha) × m	kg
Body surface area	A	0.42	m^2

3.2 | Temperature regulatory parameters and skin blood flow

Metabolism is a major factor in determining body core temperature. We used 58.2 W/m^2 as the standard power output per body surface area while resting [18] as well as a body surface area of 0.42 m^2 for the decedent. The same as the original two-node model, we assume that body thermal regulation is triggered by comparing the skin and core temperatures with their respective set points [27]. The human body will try to calibrate its skin and core temperatures to the set points through blood circulation, sweating, etc. The set points of body temperatures are not arbitrary numbers. Set points used for this study were selected from Gagge et al. (p. 722) and can be found in the coding appendix of their work [27].

3.3 | Body core and skin parameters in the two-node model

In our work, alpha is 0.05 ± 0.01 for the temperature range discussed within this paper [6]. The skin mass of the victim, then, is arrived at by factoring alpha and the body mass and thus is expressed as m_{sk} = alpha × m in which m = 10.0 kg (mass of the decedent) [26]. The core mass of the decedent was arrived at through m_{cr} = (1 − alpha) × m (see Table 4).

3.4 | Set points of body temperatures

The set point of the mean body temperature (T_{bdsp}) was determined as a weighted average of the skin/body core temperature with alpha as the weighting factor:

$$T_{bdsp} = \text{alpha} \times T_{sksp} + (1 - \text{alpha}) \times T_{crsp}$$

in which T_{sksp} and T_{crsp} are the skin and body core temperature set points, respectively [26] (Table 5).

3.5 | Body heat transfer parameters in the two-node model

The body heat transfer parameters of the decedent in the two-node model used the specific heat capacity of blood plasma. The heat capacity of plasma, c_{bl} = 3930 J/(kg·°C) is not dependent upon gender or age demographics (see, e.g., MatWeb). This number is slightly smaller than that of water, thus, reasonably accurate (plasma is 90% water). The minimal thermal conductance between the body core and the skin (in W/[m^2·°C]) is mainly due to the body tissues [29]. The specific skin and body core heat capacities are c_{sk} = 3390 J/(kg·°C) and c_{cr} = 3600 J/ (kg·°C), respectively. We note that the body's core specific heat capacity is higher than that of the skin, since the former has a higher water content. Latent heat of water vaporization is L = 2264.70 (J/g). The coefficient of the radiative heat transfer coefficient is between the body and the room and it does not consider the direct radiative exchange of heat between the heater and the body. The Stefan-Boltzmann law [37] was used to estimate the effect of this heat exchange mechanism. Due to the fact that the difference of temperature between the environment and the decedent is relatively small in our study (a few degrees at best), the Stefan-Boltzmann law can thus be linearized, leading to a radiative heat transfer coefficient h_r in W/(m^2·°C). See Table 6.

3.6 | Radiative heat loss to the room

The body temperature of 42.0°C is based on the rectal temperature of the decedent measured posthumously. Radiative heat loss may be an important way for the body to release heat under conditions discussed in the present work but it is far from being able to release all the heat metabolic functions generate. A higher radiative heat loss rate makes the body *less* likely to heat up. Thus, in our model, we use a fixed radiative heat transfer coefficient h_r = 5 W/(m^2·°C), which is approximately the upper bound as shown from calculations in this section (Table 7).

TABLE 5 Set points

Core (°C)	Skin (°C)	Mean body (°C)
36.8	33.7	36.6

3.7 | Convective heat transfer coefficient

The convective heat transfer coefficient is the maximum among the three expressions, h_{c1}, h_{c2}, and h_{c3} as first suggested in the Pierce model [6,25]. We assumed a low air velocity since the decedent was placed in an enclosed room with limited air flow. To arrive at the suppositions above, the barometric pressure, measured in mmHg, is set to 760, representing the standard atmospheric pressure [6] and is thus expressed as P_B. Note that air velocity changes in the left column of Table 8. The following equations provide the variance in difference between h_{c1}, h_{c2}, and h_{c3}:

$h_{c1} = 3.00(P_B/760)^{0.53}$ in W/(m^2·°C).
$h_{c2} = 8.60(v\,P_B/760)^{0.53}$ in W/(m^2·°C).
$h_{c3} = 5.66(M/58.2–0.85)^{0.39}$ in W/(m^2·°C).

TABLE 6 A list of physical parameters that were used to describe the thermal properties of the body of the decedent and the exchange of heat between the decedent and the room. In the text, we explain their meanings and justify the values we selected

Heat capacity of blood	c_{bl}	3930	J/(kg·°C)
Minimal thermal conductance between body core and skin	k_{min}	5.28	W·m^{-2}·°C^{-1}
Specific heat capacity of skin	c_{sk}	3390	J/(kg·°C)
Specific heat capacity of body core	c_{cr}	3600	J/(kg·°C)
Latent heat of water vaporization	L	2264.70	J/g
Coefficient of radiative heat transfer	h_r	5.00	W/(m^2·°C)
Coefficient of convective heat transfer	h_c	3.00	W/(m^2·°C)
Combined coefficient of heat transfer (unclothed and sedentary)	h	$h = h_r + h_c$	W/(m^2·°C)
Direct radiative heat transfer from the heater to the body	Q_{ht}	2.5	W
Metabolic rate per m^2 of body area	MoA	58.2	W/m^2
Metabolic rate of the decedent	M	$MoA \times A$	W
Maximum evaporative heat loss through sweating	E_{max}	$2.2h_c(P_{sk}\text{-}P_A)$	W/m^2

TABLE 7 Variables relating to radiative heat loss in the room

Stefan-Boltzmann Constant ($W\cdot m^{-2}\cdot°C^{-4}$)	Body Temperature (°C)	Environment Temperature (°C)	Emissivity	Body Surface Area (m^2)	Net Power (W)	linearized h_r ($W/(m^2\cdot°C)$)
5.67×10^{-8}	42.0	37.0	1	0.42	10.5	5.00

TABLE 8 We provide the three expressions relating to the convective heat transfer coefficient for comparison

P_B (mmHg)	760		
Air Velocity v (m/s)	h_{c1} ($W/m^2\cdot°C$)	h_{c2} ($W/m^2\cdot°C$)	h_{c3} ($W/m^2\cdot°C$)
0.00	3.00	0	2.70
0.10	3.00	2.54	2.70
0.15	3.00	3.15	2.70

with v the air velocity measured in m/s and M in the last equation representing the specific metabolic rate. It is found that $h_{c1} = 3.00$ W/($m^2\cdot$°C) is almost always the largest one for relatively low air velocities and it is also independent of the air velocity under our assumptions (Table 8).

3.8 | Direct radiative heat transfer from the heater to the body

The direct radiative heat transfer between the heater and the decedent is modeled as radiative heat exchange between two parallel plates that are 1 m apart. F_{12} is the view factor, representing the fraction of energy leaving the heater that reaches the decedent and $F_{12}(0.5\ m)^2$ gives the effective surface area. We calculated the radiative heat transfer rate between the heater and the decedent at different skin temperatures. The relative change is <20% in the temperature range of interest. Furthermore, this direct radiative heat transfer only increases the heat load of the body by ~10% on top of the metabolism heat release (~25 W), thus, its involvement in the balance of heat between the environment and the decedent is minor. In our model, we assume a steady radiative heat load to the body of 2.50 W from the heater (Table 9).

3.9 | Dependence of the Lewis relation as a function of temperature

The Lewis relation defines the ratio of evaporative to convective heat transfer for an air-vapor layer over the skin surface [27]. It is a function of temperature: LR = LR(0°C) × (T_{sk} + 273.15°C)/(273.15°C), in which T_{sk} is the skin temperature in °C [27]. As shown in Table 10, for the temperature range in concern, the Lewis relation only changes by ~4%. Hence, we assume a constant Lewis relation LR = 16.8°C/kPa or 2.2°C/mmHg in our model [27] (Table 10).

The maximum evaporative heat loss due to sweating can then be calculated as

$$E_{max} = 2.2 h_c \left(P_{sk} - P_A\right)$$

in which P_{sk} is the pressure of saturated water vapor at the skin surface and P_A is ambient vapor pressure (depending on the relative humidity). Both P_{sk} and P_A are calculated using the Antoine's equation with either the skin temperature (T_{sk}) or the room temperature (T_a) as the input parameter [6,25]:

$$P_{sk(A)} = \mathrm{Exp}\left(18.585 - 3984.92 / \left(T_{sk(a)} + 233.426\right)\right), \mathrm{mmHg}$$

3.10 | Skin blood flow

The skin blood flow rate is measured in $m^3\cdot s^{-1}\cdot m^{-2}$ (or simply $m\cdot s^{-1}$). It is defined as:

$$Bf = \left(6.3 + 200.0 \times reg_2\right) / \left(1 + 0.5 \times reg_1\right)$$

with reg_1 and reg_2 the skin and body core thermal regulation signals to control blood flow, respectively [26,27] (In [26], the authors refer to reg_1 as Sks and reg_2 as Cs on p. 524). The maximum skin blood flow is capped at 90 L/($m^2\cdot$hr) [26; p.722].

3.11 | Sweating

Typically, the most important way for the body to reduce its temperature is via sweating. This ability begins to diminish once immediate environmental temperatures reach 37–38°C when saturated vapor pressures on the skin and in air are similar to each other. Saturated vapor pressure is estimated through Antoine's Equation [26] (also see above).

4 | RESULTS

For the purposes of the simulation, the initial core/skin temperatures were set at normal (T_{sk10} = 34.1°C and T_{cr10} = 36.6°C) when the decedent was first placed in the room (t = 0). The skin, body core, and room temperatures at any point for $t > 0$ were then calculated using the adapted two-node model by solving the initial value problem defined by the various heat transfer mechanisms as described above in a stepwise manner.

In Figure 2, we show the result of our model simulation by assuming that the decedent was placed in the room before the heater

TABLE 9 These values represent the radiative heat transfer from the heater to the decedent at different temperatures

Lateral dimension of heater (m)	0.5			
Lateral dimension of decedent (m)	0.46			
F_{12}	0.059			
T_{sk} (°C)	T_{co} (°C)	T_{bd} (°C)	T_{heater} (°C)	Q_r (W)
38.0	42.0	42.0	62.5	2.34
36.0	40.0	40.0	62.5	2.55
34.0	38.0	38.0	62.5	2.76
32.0	36.0	36.0	62.5	2.95

TABLE 10 These values reflect the Lewis relation at different temperatures. Note that the LR does not change much

Temperature (°C)	0.0	30.0	34.0	38.0	42.0
LR (°C/kPa)	15.2	16.8	17.0	17.3	17.5

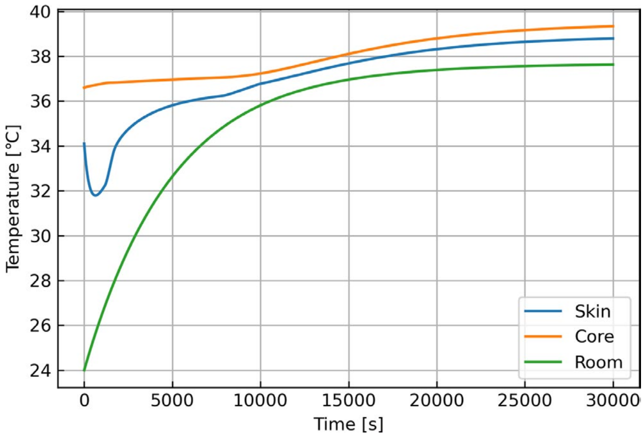

FIGURE 2 Simulation assuming the heater was turned on at the time of occupancy

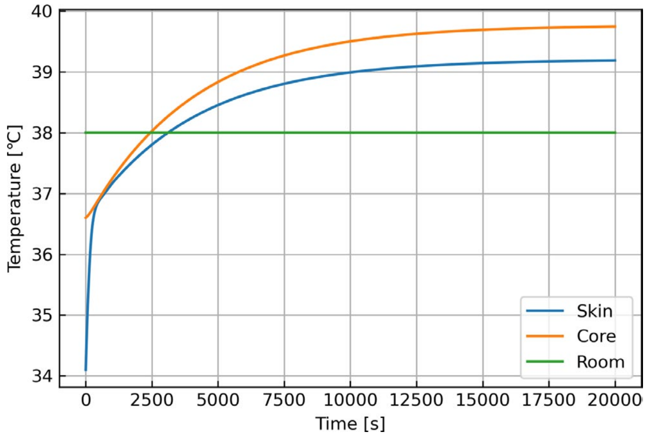

FIGURE 3 Simulation assuming the heater was turned on before occupancy

was turned on. The room temperature increased quickly for $t > 0$ and reached about 60% of its maximum value after ~4500 s (1 h and 15 min, corresponding to the time constant of the room as we found through measurements during crime scene reconstruction). Both the skin and body core temperatures only started to increase strongly after significant time delays, with the latter starting to increase appreciably after almost 10,000 s (2 h and 45 min).

Alternately, we ran another simulation that assumed a constant room temperature of 38.0°C (Figure 3), in which case the core body temperature began to rise significantly earlier than that in Figure 2. However, even in this case, it took at least 2500 s (~45 min) for the body core temperature to go above the room temperature of 38.0°C and approximately another hour is required before the body core temperature reached 39.0°C.

5 | CONCLUSION

We have successfully applied the two-node model to evaluate the environmental factors leading to the child's death, as derived from the experimental conditions enacted at the death scene. Since there is little research available in the literature of a similar nature, the importance of adding to the body of literature is underscored by an event like this. It should be noted that this effort was conducted after the event transpired and thus all data were dependent upon the accuracy of the observations made at the time by emergency officials who responded to the call for help.

The simulations also incurred some assumptions, again as an effect of recreating the event in similar, but not precisely exact, conditions. Our models seek to explain the length of time and the thermal conditions necessary to cause a hyperthermic fatality in a young child and we believe we accomplished that, even with the post-event challenges presented. Within the context of this case, we never knew for sure how long the children were in the room, how long they were subjected to the heat source, and thus can only rely on the data presented. Another effect that cannot be concretely controlled for is the relative humidity in the room at the time. When the experiment was conducted, there were not two living children in the room, and thus their respiration's effect on the RH was not factored in, although we do not believe it would greatly alter our findings (A controlled simulation using 100% RH showed little difference from results presented here based on RH = 90.0%). We do recognize that human bodies are mostly water and water has a high heat capacity, making it difficult to raise the human body temperature without any direct and strong heat transfer mechanism, such as the space heater. From the simulation, at which point the body core temperature starts to rise significantly depends upon whether the heater was switched on after the decedent was placed in the room (Figure 2) or the decedent was placed in a room that was pre-heated (Figure 3). The 2 hr 45 min (9900 s) mark as shown in Figure 2 may be coincidental and strongly dependent on when the temperature of the room becomes sufficiently high and it becomes difficult for the body to release heat. In Figure 2, this happens when the room temperature becomes ~36°C (the green curve). On the other hand, if the decedent is brought into a pre-heated room as shown in Figure 3, the core body temperature will start increasing from almost the very beginning. However, even in this case, it would take at least 45 min before the core temperature could reach the room temperature of 38.0°C.

Thus, considering the environmental factors and data derived from the experiment, along with the data collected by emergency responders, we were able to provide a window-timeframe that the decedent had to be exposed to the high heat in the room in order to reach a critical state. This was the question that was presented by officials at the onset of this case study and ultimately was focused on whether the child (really, the children) was exposed to excessive heat for a long time as suspected, or if they were outside playing 5 min before the call. We find that it is improbable that the decedent was playing as caregivers reported as he likely had to be subjected to the high temperatures for a period ranging from 45 min to 2 h and 45 min for his body core temperature to reach a dangerous level which may later lead to a hyperthermic death.

Furthermore, since law enforcement officials measured an average room temperature of 31.8°C 45 min – 1 hr after first responders arrived at the scene, considering the thermal time constant of the room of 5000 s, the room was most likely at its maximum temperature of ~38°C (with a 1500 W heater) when the heater was switched off. In this case, it would have taken the room a *minimum* of 4+ h to reach this temperature.

DISCLAIMER

The views expressed in this article are our own and not an official position of Florida A&M University.

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How to cite this article: Bushong LC, Diao Z. Fatal pediatric hyperthermia: A forensic review. J Forensic Sci. 2022;00:1–16. https://doi.org/10.1111/1556-4029.14989

APPENDIX A

Device Name Serial Number FORMATTED DATE-TIME YYYY-MM-DD HH:MM:SS	D2-2484988 2484988 Temperature (°C)	Relative humidity (%)	Heat Stress Index (°C)	Dew point (°C)
1/2/2020 20:50	21.1	48.2	20.5	9.8
1/2/2020 21:00	20.9	79.3	21.3	17.2
1/2/2020 21:10	20.3	86.2	20.7	17.9
1/2/2020 21:20	20.2	89.1	20.8	18.4
1/2/2020 21:30	20.3	91	21	18.8
1/2/2020 21:40	20.4	91.7	21.1	19
1/2/2020 21:50	20.5	91.6	21.1	19.1
1/2/2020 22:00	22.3	76.4	23	18
1/2/2020 22:10	23.1	74.4	23.6	18.3
1/2/2020 22:20	24.5	71.3	25.1	19
1/2/2020 22:30	25.4	67.7	26.2	19
1/2/2020 22:40	26.5	64.1	27.8	19.2
1/2/2020 22:50	27.3	60.8	28.5	19
1/2/2020 23:00	28.1	57.5	29.2	18.9
1/2/2020 23:10	29	55	30.6	19
1/2/2020 23:20	29.6	52.7	31.6	18.9
1/2/2020 23:30	30.1	50.1	31.9	18.5
1/2/2020 23:40	30.6	47.1	32.1	18
1/2/2020 23:50	31.1	45	32.6	17.8
1/3/2020 0:00	31.6	43.4	33.3	17.7
1/3/2020 0:10	32	41.7	33.5	17.4
1/3/2020 0:20	32.4	40.1	33.9	17.1
1/3/2020 0:30	32.7	38.6	34	16.8
1/3/2020 0:40	33	37.2	34.5	16.5
1/3/2020 0:50	33.4	36.5	35	16.6
1/3/2020 1:00	33.8	35.9	35.3	16.6
1/3/2020 1:10	34	35.2	35.4	16.4
1/3/2020 1:20	34.2	34.2	35.6	16.2
1/3/2020 1:30	34.4	33.4	35.6	15.9
1/3/2020 1:40	34.5	32.6	35.7	15.7
1/3/2020 1:50	34.7	31.6	35.7	15.4
1/3/2020 2:00	34.9	30.7	35.7	15.1
1/3/2020 2:10	35	30.1	35.6	14.8
1/3/2020 2:20	35.2	29.4	35.8	14.7
1/3/2020 2:30	35.3	28.8	35.9	14.5
1/3/2020 2:40	35.3	28.3	35.8	14.2
1/3/2020 2:50	35.6	27.7	36.2	14.2
1/3/2020 3:00	35.8	27.4	36.2	14.1
1/3/2020 3:10	35.9	26.8	36.4	13.9
1/3/2020 3:20	36	26.4	36.5	13.8
1/3/2020 3:30	36	26.1	36.4	13.6
1/3/2020 3:40	36.1	25.7	36.3	13.4
1/3/2020 3:50	36.3	25.4	36.4	13.3
1/3/2020 4:00	36.3	25.3	36.6	13.3

APPENDIX A (Continued)

Device Name Serial Number FORMATTED DATE-TIME YYYY-MM-DD HH:MM:SS	D2-2484988 2484988 Temperature (°C)	Relative humidity (%)	Heat Stress Index (°C)	Dew point (°C)
1/3/2020 4:10	36.5	24.8	36.8	13.2
1/3/2020 4:20	36.6	24.8	36.9	13.3
1/3/2020 4:30	36.7	24.6	36.9	13.2
1/3/2020 4:40	36.7	24.5	37	13.2
1/3/2020 4:50	36.8	24.4	37	13.2
1/3/2020 5:00	36.9	24.3	37.2	13.2
1/3/2020 5:10	37.1	24.5	37.4	13.5
1/3/2020 5:20	37.1	24.5	37.4	13.5
1/3/2020 5:30	37.1	24.5	37.6	13.5
1/3/2020 5:40	37.3	24.9	38	13.9
1/3/2020 5:50	37.3	25.2	38.1	14.1
1/3/2020 6:00	37.4	25.7	38.3	14.5
1/3/2020 6:10	37.4	26.5	38.6	15
1/3/2020 6:20	37.6	27	39.1	15.5
1/3/2020 6:30	37.5	27.7	39.2	15.8
1/3/2020 6:40	37.7	28.2	39.4	16.2
1/3/2020 6:50	37.6	28.8	39.6	16.4
1/3/2020 7:00	37.8	29.1	39.9	16.7
1/3/2020 7:10	37.8	29.4	40.2	17
1/3/2020 7:20	37.9	29.6	40.4	17.2
1/3/2020 7:30	38	29.8	40.7	17.3
1/3/2020 7:40	38.1	30.2	40.8	17.6
1/3/2020 7:50	38	30.6	41	17.7
1/3/2020 8:00	38.2	30.8	41.3	18
1/3/2020 8:10	38.3	31	41.5	18.2
1/3/2020 8:20	38.3	31.3	41.9	18.4
1/3/2020 8:30	38.4	31.5	42	18.5
1/3/2020 8:40	38.4	31.7	42.1	18.6
1/3/2020 8:50	38.5	31.8	42.5	18.8
1/3/2020 9:00	38.6	31.9	42.5	18.9
1/3/2020 9:10	38.6	32.2	42.9	19.1
1/3/2020 9:20	38.7	32.2	42.9	19.1
1/3/2020 9:30	38.7	32.3	43.1	19.2
1/3/2020 9:40	38.9	32.4	43.5	19.4
1/3/2020 9:50	38.9	32.4	43.5	19.4
1/3/2020 10:00	39	32.4	43.7	19.5
1/3/2020 10:10	39.1	32.5	43.8	19.6
1/3/2020 10:20	39.2	32.5	44	19.7
1/3/2020 10:30	39.1	32.7	44.1	19.8
1/3/2020 10:40	39.2	32.8	44.2	19.8
1/3/2020 10:50	39.3	32.9	44.6	20
1/3/2020 11:00	39.5	33	44.8	20.2
1/3/2020 11:10	39.5	33	44.8	20.2

(Continues)

APPENDIX A (Continued)

Device Name Serial Number FORMATTED DATE-TIME YYYY-MM-DD HH:MM:SS	D2-2484988 2484988 Temperature (°C)	Relative humidity (%)	Heat Stress Index (°C)	Dew point (°C)
1/3/2020 11:20	39.6	33.1	45.1	20.3
1/3/2020 11:30	39.8	33.1	45.5	20.5
1/3/2020 11:40	39.7	33.1	45.5	20.4
1/3/2020 11:50	39.8	33.2	45.6	20.6
1/3/2020 12:00	40	33.1	46.1	20.7
1/3/2020 12:10	40.2	33.2	46.6	21
1/3/2020 12:20	40.2	33.2	46.4	20.9
1/3/2020 12:30	40.3	33.2	46.7	21
1/3/2020 12:40	40.6	33.1	47.3	21.3
1/3/2020 12:50	40.6	33.1	47.3	21.3
1/3/2020 13:00	40.6	33.2	47.3	21.3
1/3/2020 13:10	40.7	33.3	47.6	21.4
1/3/2020 13:20	40.8	33.2	47.8	21.5
1/3/2020 13:30	41	33.2	47.9	21.6
1/3/2020 13:40	38	36.8	43.4	20.7
1/3/2020 13:50	34.4	41.2	38	19.3
1/3/2020 14:00	32.8	42.1	35	18.2
1/3/2020 14:10	31.7	42.7	33.4	17.5
1/3/2020 14:20	30.8	46.7	32.5	18.1
Device Name Serial Number FORMATTED DATE-TIME YYYY-MM-DD HH:MM:SS	**D2-2484992 2484992 Temperature (°C)**	**Relative humidity (%)**	**Heat stress index (°C)**	**Dew point (°C)**
1/2/2020 20:50	21.2	62.2	21.1	13.7
1/2/2020 21:00	20.8	77.2	21.2	16.7
1/2/2020 21:10	20.4	85	20.8	17.8
1/2/2020 21:20	20.3	88.5	20.8	18.3
1/2/2020 21:30	20.5	90.4	21.1	18.8
1/2/2020 21:40	20.6	91.2	21.3	19.1
1/2/2020 21:50	20.6	91.2	21.3	19.1
1/2/2020 22:00	23.5	72	24	18.2
1/2/2020 22:10	22.9	71.9	23.3	17.5
1/2/2020 22:20	23.5	71	23.9	17.9
1/2/2020 22:30	24.3	68.9	24.7	18.2
1/2/2020 22:40	25.2	66	25.9	18.4
1/2/2020 22:50	26	62.7	26.8	18.3
1/2/2020 23:00	26.8	59.7	27.6	18.2
1/2/2020 23:10	27.4	56.8	28.3	18.1
1/2/2020 23:20	28	54.4	28.9	18
1/2/2020 23:30	28.7	52.2	29.7	17.9
1/2/2020 23:40	29.1	49.6	30.2	17.5
1/2/2020 23:50	29.6	47.5	30.7	17.3
1/3/2020 0:00	30	45.8	31	17.1
1/3/2020 0:10	30.5	43.9	31.4	16.8

APPENDIX A (Continued)

Device Name Serial Number FORMATTED DATE-TIME YYYY-MM-DD HH:MM:SS	D2-2484992 2484992 Temperature (°C)	Relative humidity (%)	Heat stress index (°C)	Dew point (°C)
1/3/2020 0:20	30.8	42.2	31.6	16.5
1/3/2020 0:30	31.3	40.9	32	16.4
1/3/2020 0:40	31.5	39	32.3	15.9
1/3/2020 0:50	31.8	38.3	32.7	15.9
1/3/2020 1:00	32.1	37.9	33	15.9
1/3/2020 1:10	32.4	37.1	33.2	15.8
1/3/2020 1:20	32.6	36.1	33.5	15.6
1/3/2020 1:30	32.8	35.2	33.7	15.5
1/3/2020 1:40	33	34.3	33.7	15.2
1/3/2020 1:50	33.2	33.3	33.7	14.9
1/3/2020 2:00	33.3	32.4	33.8	14.6
1/3/2020 2:10	33.5	31.8	33.7	14.4
1/3/2020 2:20	33.6	30.9	33.8	14.1
1/3/2020 2:30	33.8	30.3	33.8	13.9
1/3/2020 2:40	33.9	29.8	33.8	13.8
1/3/2020 2:50	34	29.3	34	13.6
1/3/2020 3:00	34.1	28.6	34.1	13.4
1/3/2020 3:10	34.2	28	34.1	13.1
1/3/2020 3:20	34.3	27.8	34.2	13.1
1/3/2020 3:30	34.4	27.4	34.2	12.9
1/3/2020 3:40	34.5	27	34.3	12.8
1/3/2020 3:50	34.6	26.6	34.4	12.7
1/3/2020 4:00	34.8	26.5	34.5	12.7
1/3/2020 4:10	34.8	26.1	34.6	12.6
1/3/2020 4:20	34.9	26	34.7	12.6
1/3/2020 4:30	35	25.8	34.8	12.5
1/3/2020 4:40	35.1	25.7	34.8	12.5
1/3/2020 4:50	35.2	25.6	35.1	12.6
1/3/2020 5:00	35.3	25.7	35.1	12.7
1/3/2020 5:10	35.4	25.8	35.3	12.8
1/3/2020 5:20	35.4	25.6	35.4	12.8
1/3/2020 5:30	35.5	25.7	35.6	12.9
1/3/2020 5:40	35.6	25.9	35.6	13.1
1/3/2020 5:50	35.7	26.3	35.8	13.4
1/3/2020 6:00	35.8	27	36.2	13.9
1/3/2020 6:10	35.9	28	36.5	14.5
1/3/2020 6:20	36	28.5	36.9	14.9
1/3/2020 6:30	36	29	37.2	15.2
1/3/2020 6:40	36	29.7	37.3	15.6
1/3/2020 6:50	36.1	30.1	37.6	15.8
1/3/2020 7:00	36.2	30.5	37.9	16.2
1/3/2020 7:10	36.3	30.9	38	16.4
1/3/2020 7:20	36.4	31.1	38.3	16.6

(Continues)

APPENDIX A (Continued)

Device Name Serial Number FORMATTED DATE-TIME YYYY-MM-DD HH:MM:SS	D2-2484992 2484992 Temperature (°C)	Relative humidity (%)	Heat stress index (°C)	Dew point (°C)
1/3/2020 7:30	36.4	31.6	38.6	16.8
1/3/2020 7:40	36.5	31.6	38.8	17
1/3/2020 7:50	36.6	32	39.1	17.3
1/3/2020 8:00	36.6	32.2	39.1	17.4
1/3/2020 8:10	36.8	32.6	39.5	17.7
1/3/2020 8:20	36.9	32.8	39.7	17.8
1/3/2020 8:30	36.9	33.1	40	18
1/3/2020 8:40	37	33.3	40.1	18.2
1/3/2020 8:50	37	33.2	40.3	18.2
1/3/2020 9:00	37.1	33.5	40.5	18.4
1/3/2020 9:10	37.1	33.7	40.6	18.5
1/3/2020 9:20	37.2	33.8	40.6	18.6
1/3/2020 9:30	37.3	33.9	40.8	18.7
1/3/2020 9:40	37.4	33.9	41.1	18.8
1/3/2020 9:50	37.5	34	41.5	19
1/3/2020 10:00	37.6	33.8	41.6	19
1/3/2020 10:10	37.7	33.9	41.7	19.1
1/3/2020 10:20	37.7	34	41.9	19.2
1/3/2020 10:30	37.8	34.1	42.1	19.3
1/3/2020 10:40	38	34.1	42.3	19.4
1/3/2020 10:50	38	34.4	42.4	19.5
1/3/2020 11:00	38	34.4	42.6	19.6
1/3/2020 11:10	38.1	34.4	42.8	19.7
1/3/2020 11:20	38.2	34.6	43.2	19.9
1/3/2020 11:30	38.3	34.5	43.1	19.9
1/3/2020 11:40	38.4	34.6	43.6	20
1/3/2020 11:50	38.5	34.6	43.8	20.2
1/3/2020 12:00	38.6	34.7	44	20.3
1/3/2020 12:10	38.8	34.6	44.2	20.4
1/3/2020 12:20	38.9	34.6	44.6	20.5
1/3/2020 12:30	39	34.6	44.6	20.5
1/3/2020 12:40	39.1	34.9	45.1	20.8
1/3/2020 12:50	39.2	34.8	45.3	20.8
1/3/2020 13:00	39.3	34.8	45.5	20.9
1/3/2020 13:10	39.4	34.6	45.7	21
1/3/2020 13:20	39.6	34.8	45.9	21.1
1/3/2020 13:30	39.7	34.6	46.1	21.2
1/3/2020 13:40	36.4	37.5	40.8	19.6
1/3/2020 13:50	32.5	42.1	34.4	18
1/3/2020 14:00	30.3	44	31.2	16.7
1/3/2020 14:10	29.2	46.4	29.7	16.5
1/3/2020 14:20	28.9	51.2	30.1	17.8