



Development of Rubber Mattresses with Cooling Systems to Reduce the Incidence of Pressure Sores for the Elderly and Bedridden Patients

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Abstract

As of yet, no device can provide the best pressure relief; it only decreases the force exerted on the body's surface. Pressure sores may still only be avoided by physical therapy. Mattress climate is a critical factor in producing thermal comfort conditions when sleeping. This research examines a straightforward rubber mattress design with a thermoelectric air-cooling mechanism to lower the risk of pressure sores. The inlet cooling air temperature is maintained constant at 21 °C. The response of 10 volunteers lay awake on the mattress to the surface temperature at control room temperatures: switched on (25-26 °C) and switched off (29-30 °C) air conditioning system. It was found that thermoelectric air cooling significantly affects the mattress's temperature and moisture ventilation. Compared to mattresses without air conditioning, the temperature at different locations from the thermoelectric air-cooling box is lower, about 3-5 °C. The mattress temperature at the upper zone is the highest value, and the lower zone is the lowest. Therefore, to reduce the danger of pressure sores in the elderly and bedridden patients, this system could be a substitute for constructing a cooling mattress.

Keywords: Cooling systems; Mattresses; Pressure sores; Elderly; Bedridden patients.

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1. Introduction

Pressure ulcers (PUs) are the most prevalent condition in healthcare systems globally.^[1] Pressure or pressure mixed with shear and/or friction causes localized skin and/or underlying tissue damage. Pressure ulcers are persistent sores due to

physical disability.^[2] Prolonged compression of the tissue reduces or blocks microcirculation to a specific location. This results in a lack of oxygen in the tissues and ischemia. There are several types of pressure injuries to the skin above the bone. The range of tissue disruption can be determined from a surface injury to skin loss or a wound of unknown depth,^[3] which the PUs are becoming increasingly common among the bedridden population. It has been found that in 26% of hospital units,^[4] 43 % of nursing home residents, and 39% of patients with spinal cord injuries,^[5] the PUs were once considered unavoidable. However, it is seen as an avoidable adverse event that substantially influences the standard of medical care.^[6] Despite international guidelines and a wealth of evidence regarding the causes and prevention of PUs, they continue to occur in large numbers, and the rate of increase has remained for decades.^[7] Reports of pressure ulcer cases between 3.6% and 38%.^[8-10] PUs are related to quality of health,^[11] pain,^[12] increased morbidity,^[13] death,^[14] and financial costs.^[15] Many studies have found that pressure ulcers can be prevented.^[16,17] The volume of patients in ICUs is usually more than in general

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wards.^[18-20] However, many reports are ready to help medical teams take steps to prevent pressure sores. This is especially true for critically ill, high-risk patients,^[21] but there is still a lack of knowledge and clarity about care and action.^[22] Because of rising healthcare expenditures, PU prevention has garnered much attention, especially in a growing elderly population;^[23] preventing and treating pressure ulcers requires large and limited resources, including nursing and finance.^[15]

Many governments have decided to implement sanctions to minimize the number of pressure ulcer occurrences. For example, the US Centers for Medicare & Medicaid Services has stopped reimbursing patient-related treatments with stage 3 or 4 cases.^[24] The economic costs of pressure ulcer patients range from \$9.1 to \$ 11.6 billion annually^[25] for the USA. In the United Kingdom, the cost of pressure ulcer patients varied from £1.4 to 2.1 billion per year in 1999-2000, accounting for 4% of overall National Health Service expenses.^[26] Treating a single stage 4 pressure ulcer in Australia is around A\$61,000.^[27] According to a literature study, the cost of treating pressure ulcers per patient daily is substantially more than avoiding them.^[28] As a result, pressure ulcer avoidance is a critical component of patient care. Additional focus on pressure ulcer prevention is anticipated to enhance patient care while lowering treatment costs.^[29] There are several methods for treating and preventing pressure ulcers in patients. Nutrition and hydration intake, for example, are critical in the skin cell system and tissue healing in individuals with pressure ulcers.^[30] Various treatments are used to treat pressure ulcers. This comprises therapies to preserve and encourage wound healing (dressing, topical care, and extra treatments), stimulation light therapy, vacuum assist equipment, and wound surgery.^[31,32] Different treatment methods and prevention methods are used to help, such as support surfaces for patients with pressure ulcers. Various support surfaces have been reported, including compressed air beds, alternating pressure beds, and cushions.^[33-36] We found from the reports that improving pressure ulcers (including wound reduction rate and wound length) in patients using certain air-compressed beds has better results than standard hospital beds.^[37,38] Treatment is comparable to alternating pressure mattresses and support surfaces.^[39-41] Different forms of alternating-pressure mattresses have comparable advantages.^[42-44] According to some research, minimal air loss beds are equivalent to foam mattresses,^[45] and wound healing is comparable when comparing a mattress with a small quantity of air released to a stacked bed with a small amount of air released.

Sweating is the body's way of regulating excessive heat, but if the perspiration isn't cleaned up right enough, bacteria

can break it down into lactic acid and ammonia, which gives off a distinct stink. The power output varies between 5 and 50 $\mu\text{W}/\text{cm}^2$.^[46] The body's heat emission can be used to track the metabolic rate. During physical activity, the heat generated increases to 77 $\mu\text{W}/\text{cm}^2$ from 3.8 $\mu\text{W}/\text{cm}^2$ during rest.^[47] The heat generated is around 20–50 $\mu\text{W}/\text{cm}^2$ at 28°C.^[48,49] In addition, younger people emit 42 $\mu\text{W}/\text{cm}^2$ of heat, compared to older people's 35 $\mu\text{W}/\text{cm}^2$.^[50] Several literature reviews found that body skin temperatures varied depending on the region. **Table 1** shows the average skin temperature at various sites,^[51-53] comparable to the data provided by Ref. [54,55]. The information suggests that the healthiest circumstances are generated in low-temperature environments. Skin temperature rises by 4 °C for every 10 °C increase in outside air temperature. Mattresses, bed linens, and pillows have been shown to produce significant amounts of particle and gaseous pollution.^[56-60] Pollutants from other room occupants may re-suspend and become airborne, which might result in inhalation. Air circulation is a typical technique used to enhance air quality by venting the whole volume of the space. According to the ANSI/ASHRAE standard, hospitals must have four to six air changes per hour,^[61] while residential buildings must have ventilation of 0.217–0.74 L/sm².^[62] More sophisticated and energy-efficient ventilation techniques, such as air filtration pillows,^[63] bedside personalized ventilation,^[64] and ambient air cooling systems,^[65] have been the subject of studies. Works have shown the relation between the quality of sleep and the surroundings around the bed. These techniques affected the quality of breathed air by supplying clean air to the area around the bed occupant. Instead of successfully eliminating bed-generated pollution from the room, this method causes it to spread throughout. A completely different ventilation technique may be employed to eliminate the pollutants.

Table 1. Average human skin temperature readings at various locations.

Body Positions	(Yang <i>et al.</i> , 2011) (T _{air} = 17°C)	(Zaproudina <i>et al.</i> , 2008) (T _{air} = 23.5°C)	(Webb <i>et al.</i> , 1992) (T _{air} = 27°C)
Forehead	29.5	34.1	35.2
Neck	31.1	33.2	35.1
Back	30.6	32.5	34.4
Chest	30.3	32.3	34.4
Arm anterior	30.3	31.7	33.2
Forearm	29.5	31.5	34.0
Thigh	28.3	30.8	33.0
Calf	29.4	31.3	31.6
Foot dorsal	27.1	28.6	30.4

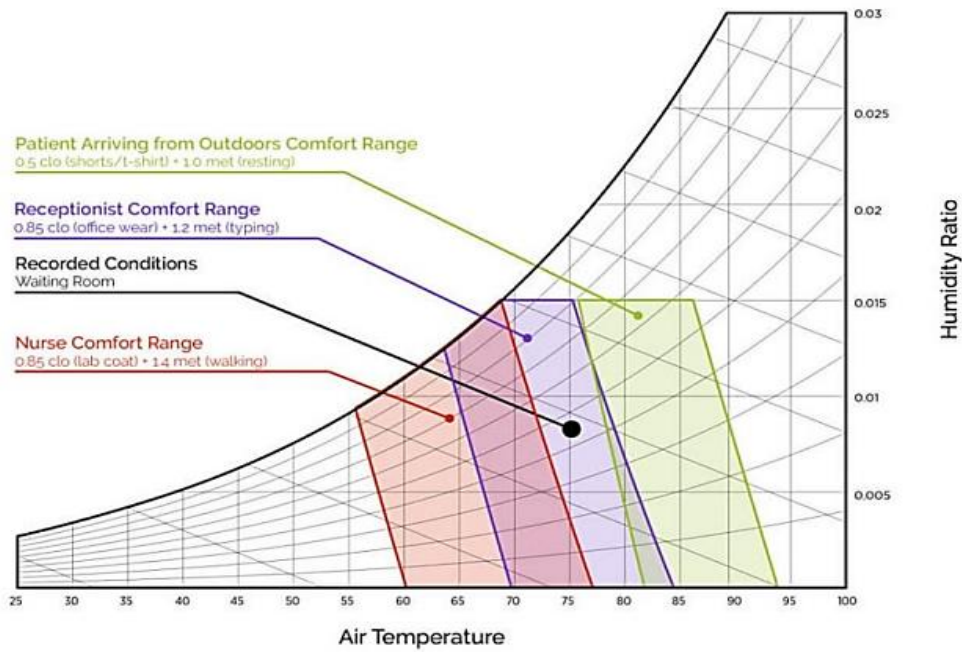


Fig. 1 Psychrometric diagram for the comfort zone in healthcare. [61,62]

Health and sleep quality in bed depend on thermal comfort. [66] When you sleep, the heat that escapes your body from your body can be lessened using bedcovers. As seen in Fig. 1, the thermal comfort zone is impacted more by a thermally insulated bed micro-environment than by the thermal environment. [67] Various techniques for supplying heat or varied ways for cooling, combinations of bedding goods with different thermal insulation, drape, tucking, and electric blankets [68] are done. The bedsore prevention mattresses are

divided into three types: Air beds or air mattresses, which are divided into two commonly used types. Cross-shaped air mattress: can provide better pressure relief. Reduce the chance of the wound being in contact with the bed surface for a long time. It uses the power of an electric air pump to move the bed over time. Honeycomb air mattress: Honeycomb air mattress Looks like a bubble and can be collapsed alternately on the bed. They have advantages and disadvantages, as shown in Table 2.

Table 2. The advantages and disadvantages of different mattresses.

Topics	Latex mattress that prevents pressure sores	Foam mattress	Curly air mattress	Honeycomb air mattress
Working principle	Distribute pressure	Distribute pressure	Switch pressure	Switch pressure
Safety	High (No electricity required)	High (No electricity required)	Low-high (Must have a notification of import details)	Low-high (Must have a notification of import details)
Sleeping comfort	A lot (The bed didn't move)	A lot (The bed didn't move)	Moderate (Switch the curls)	Medium-low (Switch the buttons)
Bear weight	200 kg	80-200 kg (Depending on model)	80 kg	80 kg
Suitability for the wound level	Suitable for all levels of severity of pressure sores	Suitable for patients who do not have wounds or level 1-2 wounds	Suitable for patients who do not have wounds or level 1-2 wounds	Suitable for patients who do not have wounds or level 1-2 wounds
Limitations	Not resistant to UV rays	Source of accumulation of dust, dust mites, bacteria, mold, and various germs	There may be a problem if the power goes out	There may be a problem if the power goes out

In addition, mattresses with phase change materials, water-cooled mattresses, and cold air delivery into the mattress microclimate are now available.^[69,70] Task air cooling systems based on beds have been investigated.^[71] According to Muzet *et al.*,^[72] even though the environmental temperature ranged between 16 and 25 °C, the mattress's temperature ranged between 28 and 31 °C. Okamoto-Mizuno and Tsuzuki obtained that the mattress temperature was maintained at around 32 - 34 °C.^[73] The observed fluctuations in bed temperature might be attributed to notable variances among individuals about their favored thermal microenvironment in bed, the instability of garment insulation and bedding systems' thermal resistance, the documented differences in bed temperature, and varied air infiltration between the body covering and the mattress. Next, Bivolarova *et al.*^[74] and Song *et al.*^[75] investigated the effectiveness of a ventilated mattress as a bed-integrated local exhaust ventilation system in conjunction with an air-cleaning fabric. The vented mattress's design was enhanced by using local heating of 30 people while lying awake on a vented mattress at room temperature. Next, Hu *et al.*^[76] and Sanati *et al.*^[77] studied on the organic shape-stabilized phase change materials and inhibition of asphaltene precipitation using hydrophobic deep eutectic solvents and ionic liquid.

PU's decrease the quality of life due to pain, resulting in higher management processes and a long time stay in the hospital. It also contributes to the rapid death of some cases.^[46] As a result, any intervention that may help prevent or treat pressure ulcers may be useful in lowering the cost of pressure ulcer care and improving the quality of life of affected patients.^[47] From the study of the literature mentioned above, it was found that there has been no study on the improvement or development of internal air circulation in air beds. As a result, this research aimed to create frequently used air beds that control airflow in and out of the air mattress to aid in ventilation and air circulation for patients, hence reducing the occurrence of PUs. However, the first part of this research is to build the cooling system and determine the best conditions, which necessitates the installation of multiple sensors or equipment to monitor different parameters continuously. It is difficult to conduct tests on bedridden or elderly patients and disturb the rest of the bedridden or elderly patients. Therefore, the first research was conducted on healthy Thai students. However, suppose the cooling system's working conditions are suitable, including appropriate climate adjustment conditions. In that case, installing specific equipment or testing procedures may not be required as it has been thoroughly tested on bedridden patients or older people, which will be the next step in future work.

2. Experimental facilities and procedure

2.1 Experimental facilities

A test room with a width, length, and height of 5.00 m × 8.50 m × 3.50 m was used to imitate a bedroom. The experimental process was performed both with and without an air conditioning system. Maintaining the air velocity inside the restricted area below 0.1 m/s was possible. The prototype aims to regulate the mattress's temperature to give the user thermal comfort. A thermoelectric air-cooling system was used to transfer the heat from the human body. Fig. 2 shows the mattress, the thermoelectric air-cooling box (35 cm × 25 cm × 25 cm), the data acquisition system, and the electric heater pads (85 cm × 45 cm). The experiment uses a 90 cm wide by 198 cm long mattress with a 20.5 cm thick mattress fabricated from rubber.

Figure 3 shows four rubber tubes were placed into the rubber mattress along the bed, below the mattress surface of 2 cm. Before the air entered the rubber tubes, it was cooled to 21 °C using a thermoelectric air-cooling box. The cold air was induced from the chamber and forced into four rubber tubes at the head zone, where it was fan-driven to the opposite closed end (foot zone). There are 34 holes with a diameter of 5 mm to enable cold air to pass from the rubber tubes to the subject's body on the mattress, chilling and ventilating the air beneath the blanket before exiting the blanket via different channels surrounding the subject, as illustrated in Figs. 3 and 4.

The damper's adjustment and the fan's speed control the airflow rate. The mattress surface temperatures (human skin temperatures) are monitored using Type-T copper-constantan thermocouples with a ±1 °C uncertainty and a data taker (DT85) with a 0.01 percent accuracy. All thermocouples are pre-calibrated using a dry box temperature calibrator.

Three sensors were used to detect the humidity while the subject was lying on the mattress, and eighteen thermocouples were employed to measure variations in the temperature of the mattress (subject) under the cover, as shown in Fig. 4. These precautions were taken to monitor the stability and uniformity of the air temperature, which the heating pad uses between thirty and fifty watts of electricity, adjusted by the variac. During the exposure, the volunteers wore their pajamas. Before the experiment, they were instructed to abstain from alcohol and caffeine-containing beverages and to take it easy over the trial days. The volunteers were briefed about the experimental protocol and the questionnaires before the commencement of the studies.

Mattresses with a latex layer are 100% real, with a different production process. The mattress layers will not go through the compressing and mixing process, but they will be produced from real natural latex, which is concentrated. When

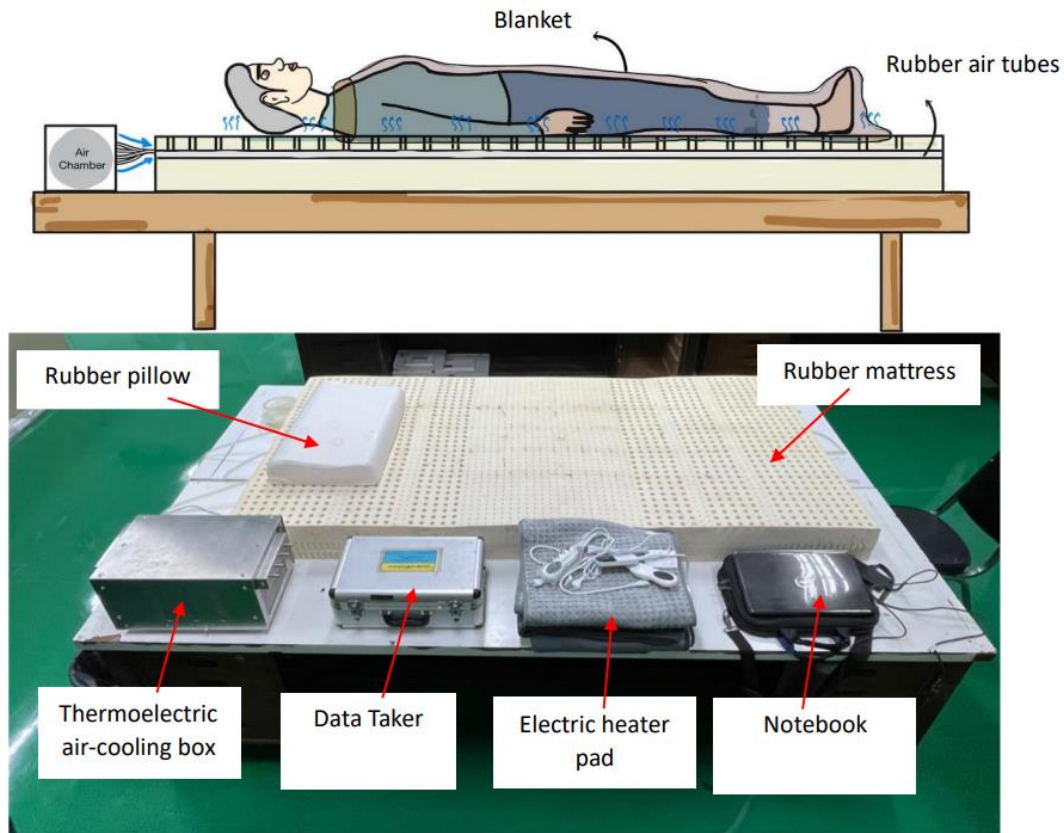


Fig. 2 Photograph of experimental facilities.

measuring softness or hardness, higher mass and weight mean denser. This makes the rubber layer soft and firm and supports the sleeper's body well. However, 100% natural latex mattresses are more expensive than compressed ones.

2.2 Thermoelectric cooling module

The aim is to regulate the mattress's temperature as in the thermal comfort. A thermoelectric device cools the inside air, transferring heat to the human body via that interface. Fig. 3a

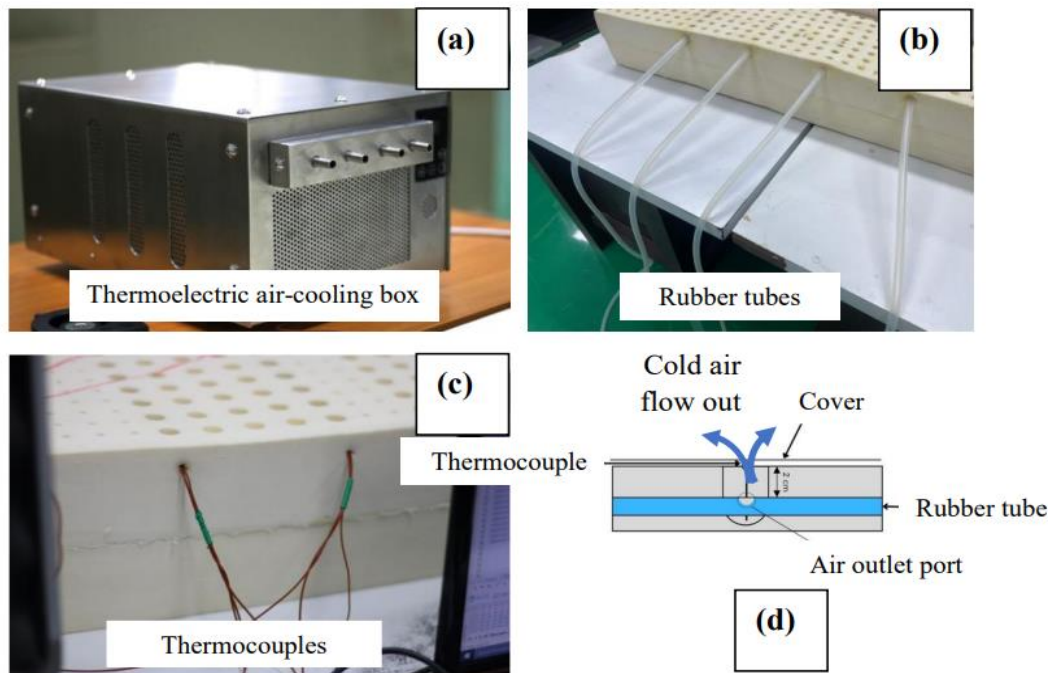


Fig. 3 shows a photograph of (a) a thermoelectric air-cooling box, (b) the rubber tube installation, (c) the thermocouple installation, and (d) the outlet airport location.

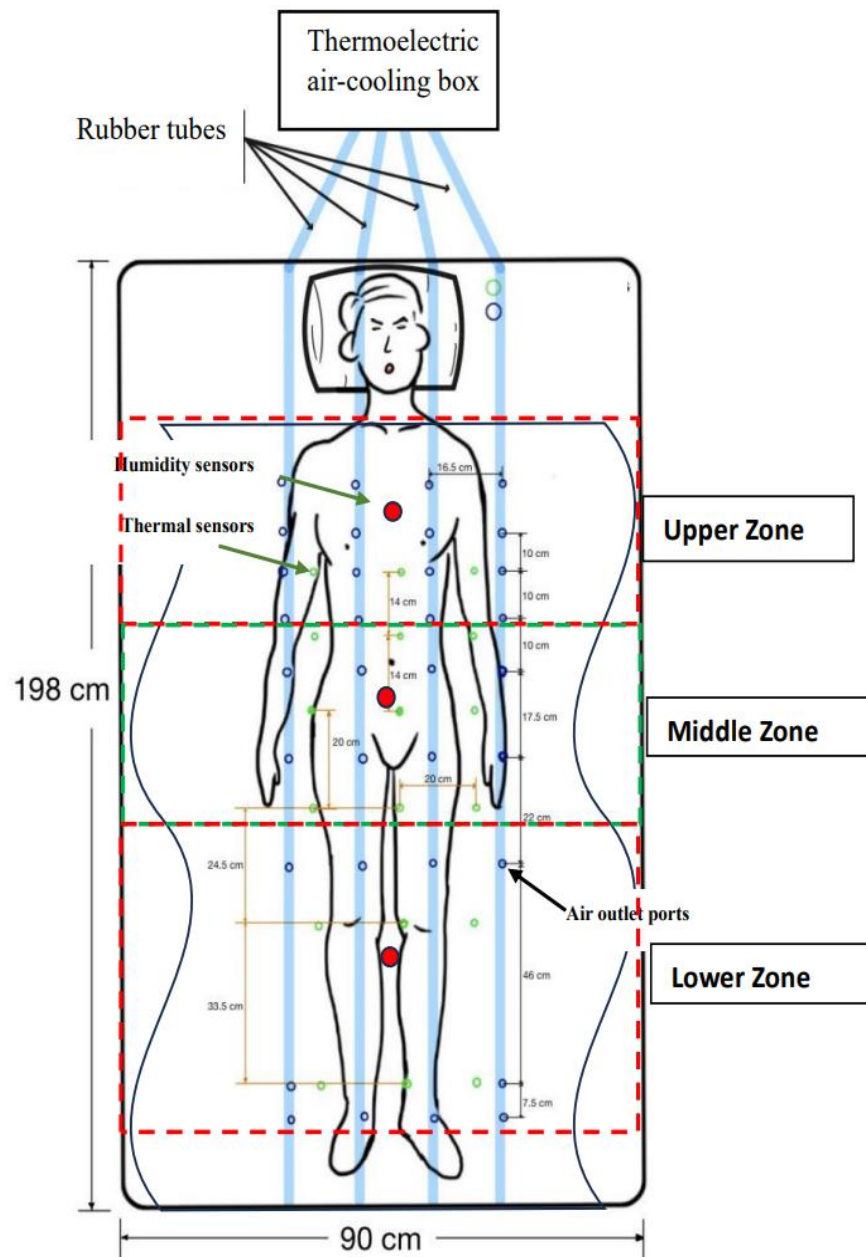


Fig. 4 shows the measured temperature and air outlet port positions.

displays the prototype of the thermoelectric air-cooling box (TACB) comprising four thermoelectric plates. With a maximum voltage of 15 V and a maximum power of about 85 W, each module has dimensions of $40 \times 40 \times 4$ mm. The modules are installed between two finned heat sinks and are electrically linked in a series. Considering the extraordinarily high heat flux density that can be reached on the tiny surface of thermoelectric, two sinks serve as heat exchangers. Four axial fans are installed to provide forced convection.

2.3 Experimental conditions

Every participant engaged in two experimental sessions, conducted at two distinct room temperatures: thirty degrees

Celsius without air conditioning and twenty-seven degrees Celsius with air conditioning. For each subject, the experiment has been performed twice (two days gap) with and without air conditioning. 30 °C room temperature represents the normal indoor conditions during wet seasons (Thailand). The range was chosen to be almost in line with the bedroom temperature that has been covered in the literature,^[78] as well as the indoor climate requirements^[79] and hospital patient rooms.^[62] Throughout every testing session, the chamber's relative humidity (RH) remained constant within the 40–50 %RH without any control. The experiment was divided into four categories: without the heat load (without electric heating pad), with heat load from the electric heating pad without the

blanket, the heat load from the electric heating pad, and healthy human individuals (five males and five females) were recruited to participate in the studies, and two heating pads (85 cm × 45 cm) were employed as the load from the human body for the precautions monitor the stability and uniformity of the mattress temperature, as shown in Fig. 5. Every experiment mode was run for two hours at the steady state temperature, and nearly all participants kept their arms underneath the blanket. A cover with a thickness of 1.5 cm and a weight of 0.24 kg/m² was placed over the individuals. The individuals were free to roam about while being instructed to lie on their backs. The initial step of this study is to establish the cooling system and find the optimal conditions, which need the installation of several sensors or equipment to monitor various parameters continually. Conducting tests on bedridden or elderly patients without disturbing the other bedridden or elderly patients is challenging. Thus, the study was carried out on ten healthy Thai students-five males and five females—who were chosen as subjects to reduce differences in age, body type, and lifestyle. Table 3 displays the subject's data. The subjects were acquainted with the bedding utilized in the experiment and followed identical daily schedules. All volunteers gave their consent and underwent basic instructions

relevant to the study, which covered the purpose of the questionnaires, how the experimental equipment worked, and what needed attention. The day before the trial, stimulant foods and medications, including alcohol and caffeine, were prohibited. Table 4 lists the instruments utilized in this investigation and their accuracy and uncertainty.

Table 3. Basic data about the subjects.

Subjects	Male (Mean±SD)	Female (Mean±SD)	Overall (Mean±SD)
Age (year)	21±0.00	21±0.00	21±0.00
Height (cm)	171±0.01	163±0.02	167±0.01
Weight (kg)	60.67±4.04	52.00±6.08	56.33±5.06
BMI	20.83±1.37	19.48±2.06	20.15±1.72

Table 4. Accuracy and uncertainty of measurements.

Instrument	Accuracy (%)	Uncertainty
Anemometer	0.1	±0.2
Dry-box temperature calibrator	0.1	±0.1
Data Taker & type T thermocouple	0.1	±0.1
DC voltage and current sensor	0.1	±0.01
AC digital power energy meter	0.1	±0.01

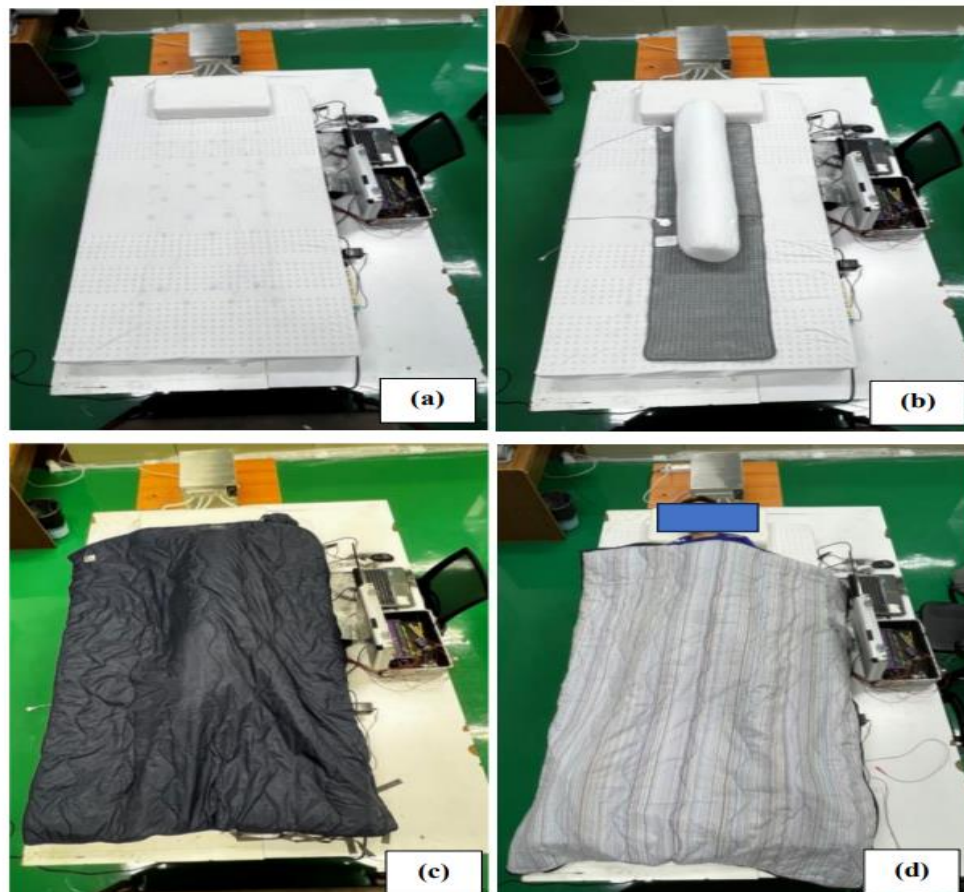


Fig. 5 shows a photograph of subjects lying on the rubber mattress (a) without heat load, (b) load from an electric heating pad without the blanket, (c) heat load from an electric heating pad, and (d) heat load from humans.

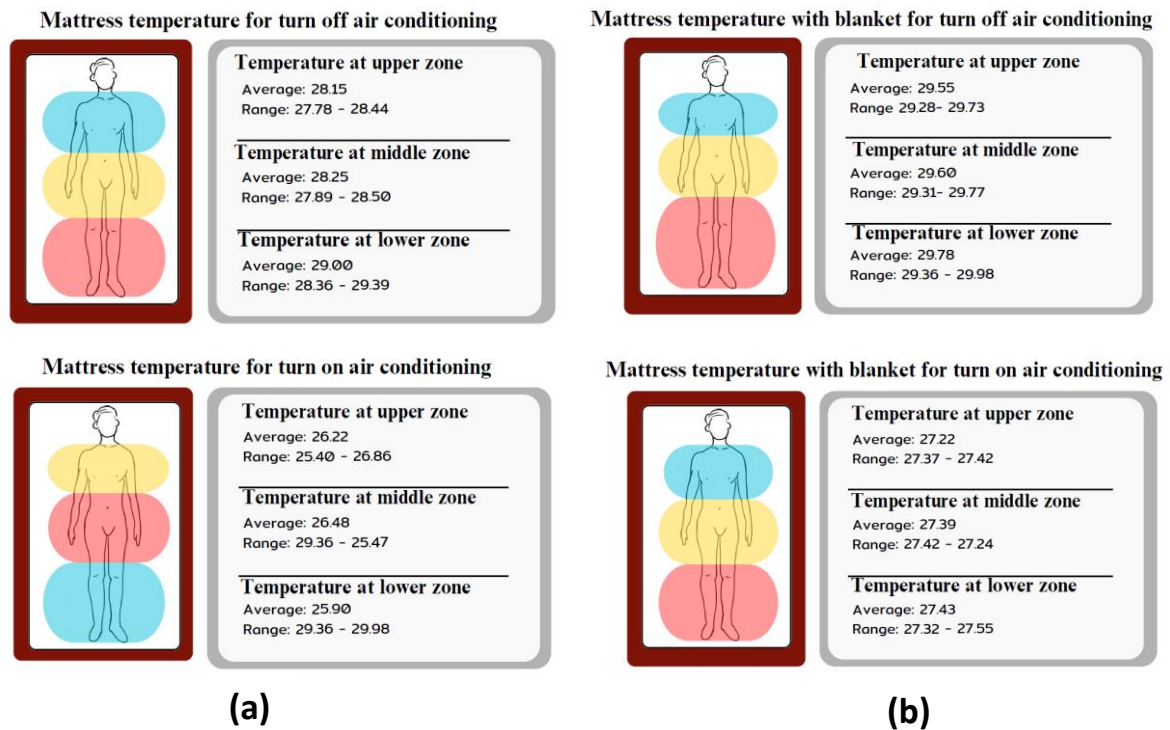


Fig. 6 shows the mattress temperature distribution without and with the blanket for (a) turn-off and (b) turn-on air conditioning.

3. Results and Discussion

The usual wintertime interior temperatures in Nakhornnayok, Thailand, were used to describe the thermal environment parameters. Due to variations in interior temperature and measurement inaccuracy from the equipment, the actual thermal environment parameters differed somewhat from the normal temperatures. Since the study was concerned with thermal comfort at room temperature variances of ± 5 °C, the discrepancies did not affect the validity of the findings.

During the day, the operational procedures were carried out in a test room measuring 4.00 m \times 7.50 m \times 2.50 m in width,

length, and height, both with and without air conditioning. A 90 cm wide mattress, 198 cm long, with 20.5 cm thickness, is used in the experiment. The rubber mattress temperature fluctuations were monitored using eighteen thermocouples for 120 minutes. First, as Fig. 5a illustrates, each study has been conducted to examine the mattress temperature in the absence of a heat load for 120 minutes. These precautionary procedures were implemented to monitor the stability and consistency of the surrounding air temperature. The air temperature in the test room was set to 25 °C while the air conditioning was turned on and 30 °C when turned off. In the presented results, three

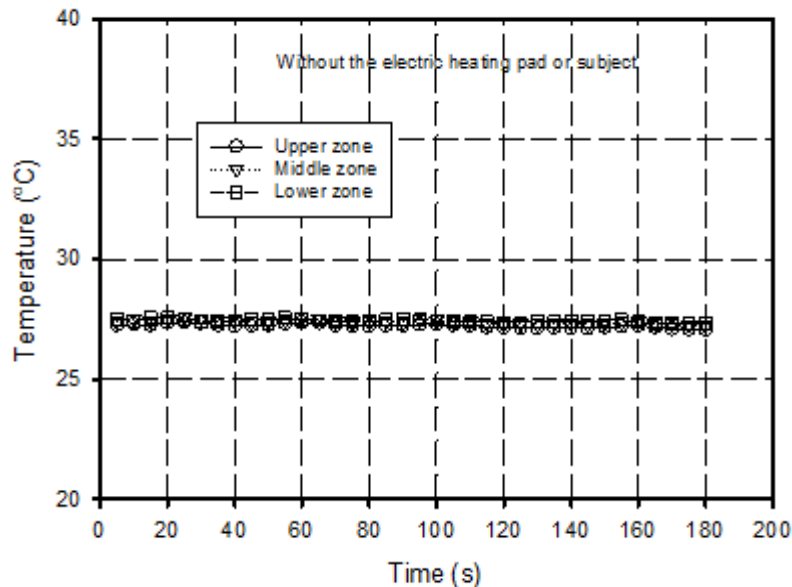


Fig. 7 shows the variation of the mattress temperature (without the electric heating pad or subject) with operating time.

zones are identified by the mattress temperature: upper zone (shoulder and upper body), middle zone (lower torso and hips), and lower zone (legs). It was feasible to keep the air velocity inside the confined region below 0.1 m/s by monitoring the air velocity surrounding the bed. Fig. 6a shows that to switch off the air conditioning, the mattress temperature (without blanket) at different zones has similar values, which the mattress temperatures at the upper, middle, and lower zones are 28.15 °C, 28.25 °C, and 29.00 °C, respectively. The mattress temperature in each zone for the turned-off air conditioning is close, with a percentage difference of about 2.21%. The average mattress temperature when turned on is 8.29 % lower than when turned off. Fig. 6b shows that the average mattress temperatures for a covered mattress with a blanket are 4.05 % and 4.28 % higher without a blanket when the air conditioning is turned on and off, respectively. The experiment was performed without the cover or subject on the mattress to ensure the temperature sensors at different zones were stable and uniform. Fig. 7 shows the precautionary monitoring of mattress temperature at various zones. The mattress temperatures at different zones are close, as shown in Fig. 7.

In addition, experiments were done with the electric heater pad with the covered blanket for turned-off and turn-on air conditioning, as shown in Fig. 8. Two electric heating pads (85 cm × 45 cm) were employed as the load from the human body, as shown in Fig. 5b. The generated heat from the electric heater pad is 10.5 W, accumulated under the blanket. Therefore, the mattress temperatures at three distinct locations rise with increasing operation time, reaching a high of 36 °C and 38 °C for turn-on and turn-off cases, respectively, and remaining virtually constant. From Fig. 9, both experimental conditions show that the mattress temperatures for turn-on air

conditioning are lower than for turn-off air conditioning. This means that room temperature affects the mattress temperature for the covered blanket.

Every experiment mode was run for two hours at either the steady state temperature or a lower one, and nearly all participants kept their arms underneath the blanket. The individuals were free to roam about while being instructed to lie on their backs. Ten healthy Thai students—five males and five females—were chosen as subjects to reduce differences in age, body type, and lifestyle. Table 3 displays the subject's data. The subjects were acquainted with the bedding utilized in the experiment and followed identical daily schedules. All volunteers gave their consent and underwent basic instructions relevant to the study, which covered the purpose of the questionnaires, how the experimental equipment worked, and what needed attention.

Figure 9 illustrates the mattress temperature at several locations without a thermoelectric air-cooling box (TACB). The mattress temperature changed over 120 minutes primarily due to the interior temperature and heat loss from the human body. Due to the accumulated heat from the human body, the mattress temperature tends to increase with the maximum value of 35.5 °C with increasing operating time. As seen in Fig. 9, the mattress temperature grew progressively to its greatest level in stage I and remained almost steady in stage II. The four basic ways heat is released from the human body are evaporation, convection, radiation, and conduction. The body's metabolism, which intensifies during work, produces heat continually. During this time, airflow over the skin facilitates metabolic cooling. The human body comprises many thermoregulation physiologies in the limbs, feet, hands, head, and torso. Surface area, tissue conductivity, local heat

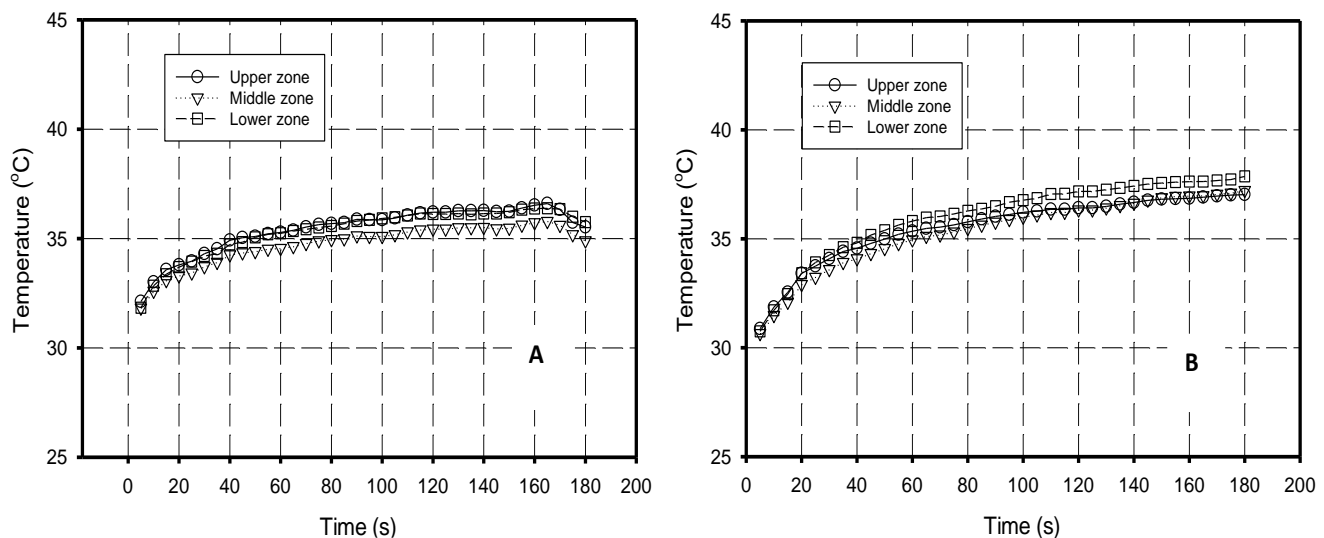


Fig. 8 shows the variation of the mattress temperature (blanket covering the electric heating pad) with operating time for (A) turned-on and (B) turned-off air conditioning.

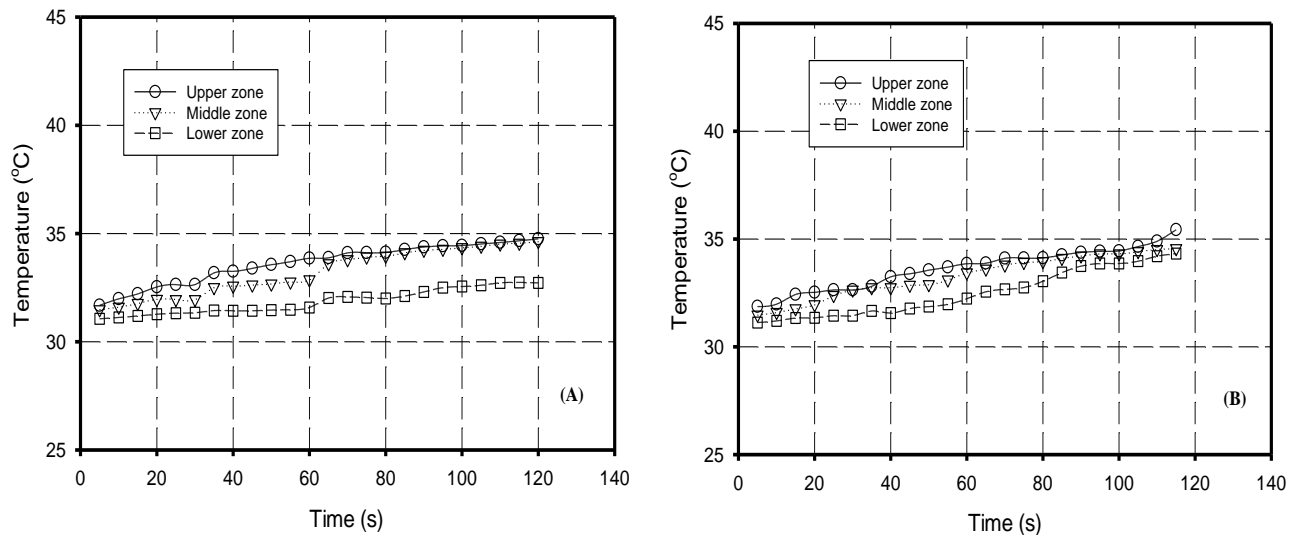


Fig. 9 shows the variation of the mattress temperature (subject laying) with operating time for (A) turned-on and (B) turn-off air conditioning.

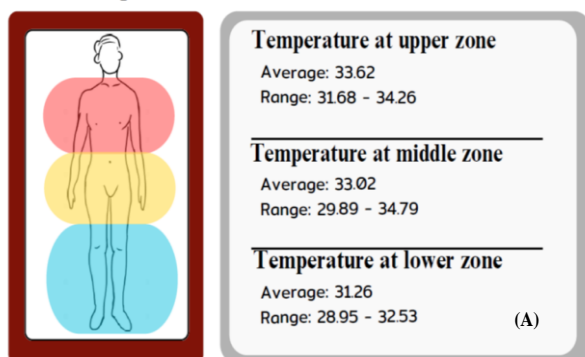
production, and other variables affect heat transport. It is indicated that various bodily sections have varying cooling requirements. The average maximum and minimum temperatures occur at the upper and lower zones. When the air conditioning is switched on, the mattress temperatures are lower than when it is turned off, as shown in Fig. 10.

There are many phases for pressure ulcers. However, the most frequently applied kind is the division of distance based on the depth of the wound, as Shea's categorization.^[80] This has four stages: Phase 1 is when the pressured region starts to red. There are no fissures since the skins are still adhered to one another. Phase 2: The skin begins to peel off in some areas. A red, shallow wound is called a keratin. Stage 3: The tendon, muscle, and bone are still normal, and there is no longer a wound when the wound reaches the subcutaneous layer. Stage 4: The wound may be discovered deep into the muscle, tendon, or bone structures. There are two approaches to pressure sore prevention: primary prevention, which occurs before the sores appear, and secondary prevention, which aims to stop the sores from returning once they have already appeared (Secondary

prevention). There is yet no gadget that can offer the finest pressure alleviation at this time. It only lessens the force applied to the body's surface. Physical therapy, which involves changing the patient onto their side every two hours, is still the most effective way to prevent pressure sores from developing. In conjunction with changing the patient onto their side every two hours, physical therapy and the mattress temperature are still the most effective ways to prevent pressure sores from developing. Patients with pressure ulcers can benefit from various treatment and preventative strategies, including using support surfaces. There have been reports of different support surfaces, including cushions, alternating pressure beds, compressed air beds,^[33-35] and mattress temperature.^[36]

According to research, individuals utilizing specific air-compressed beds have better outcomes than those using regular hospital beds when treating pressure ulcers (including wound reduction rate and length).^[37,38] Alternating pressure mattresses and other support surfaces are treated similarly.^[39-41] We designed the experimental system under comparable operating circumstances to validate the desired outcomes.

Mattress temperature with human for turn off air conditioning



Mattress temperature with human for turn on air conditioning

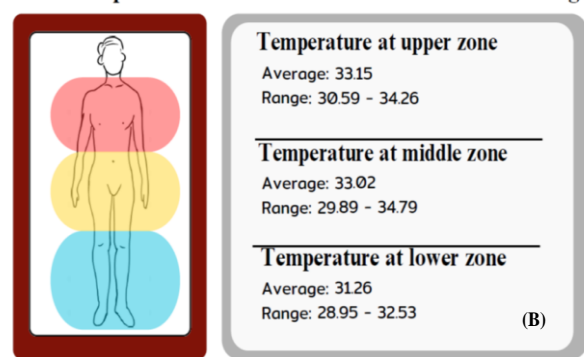


Fig. 10 shows the average mattress temperature distribution with human for (A) turned-off and (B) turn-on air conditioning.

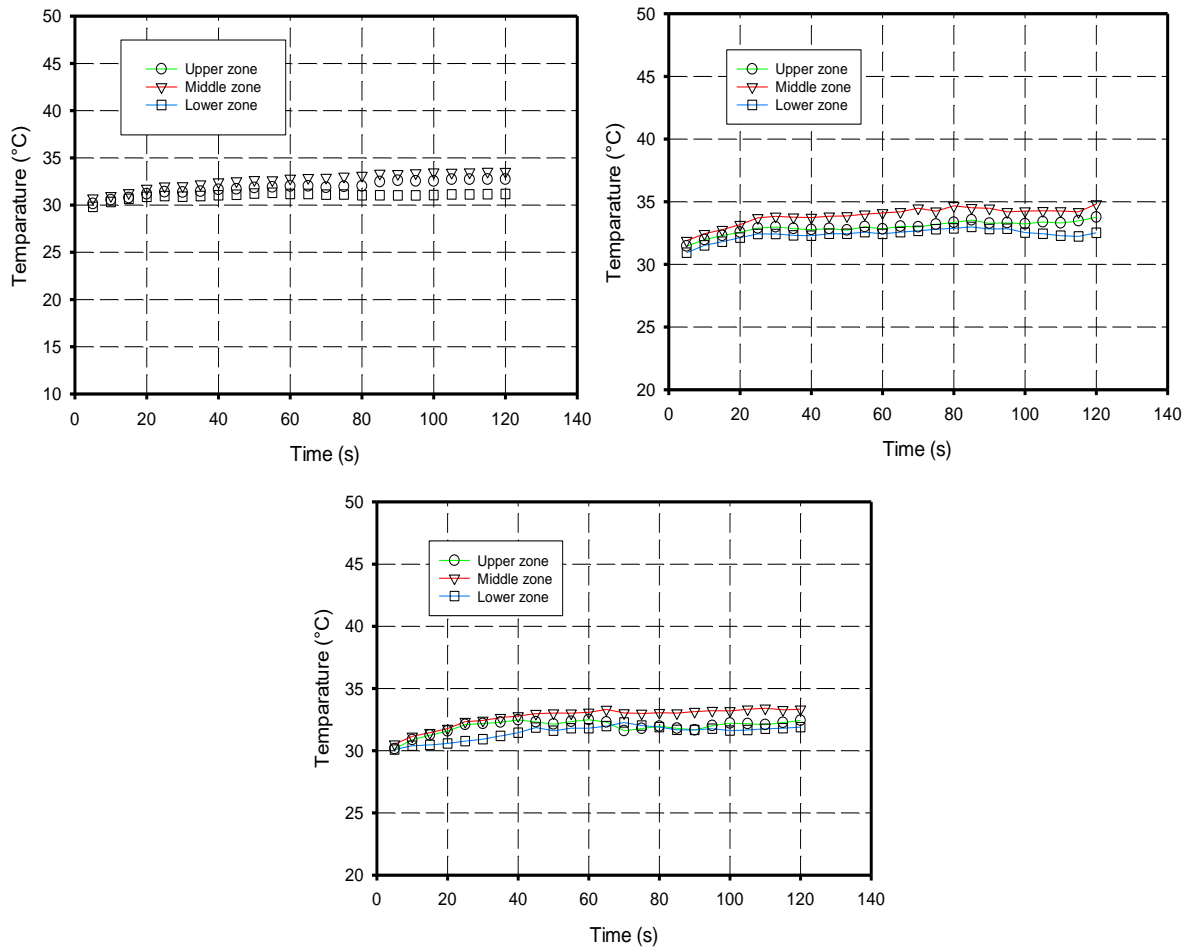


Fig. 11 shows the mattress temperature distribution with a thermoelectric air-cooling box (TACB) from three males.

The average back temperatures are also compared with the suggested findings,^[51–53] as Table 1 illustrates. The average back temperature errors obtained by Yang *et al.*,^[51] Zaproudina *et al.*,^[52] and Webb *et al.*^[53] are 8.00 %, 1.98 %, and 3.70 %, respectively. As the results show above, the prototype seeks to control the uniform temperature at the human-mattress interface to provide the user with thermal comfort. A thermoelectric device transfers heat to the body by heating or cooling the inside air. Cool air at 21 °C is forced into four rubber tubes placed into the rubber mattress at the head zone and flows along the tube to the other closed end (feet zone) by a fan. There are 34 holes with a 5 mm diameter to allow cold air to flow out of the bed, as shown in Fig. 4.

Figures 11 and 12 show the variation of the mattress temperature with a thermoelectric air-cooling box for three males and females, respectively. The inlet cold air temperature from the thermoelectric air-cooling box is set to 21°C. The average mattress temperature at three zones increases 40 minutes after the operation and remains nearly constant. The thermoelectric air-cooling box decreased the mattress temperature by 3-5 °C, and 3-4 °C for females and males,

respectively. For all volunteers, the maximum temperature of the mattress is less than 33 °C, reducing the Pus occasion. Skin temperature increases with the increase in tissue metabolic, with a 10% increase in metabolic demand per 1°C rise in skin temperature.^[81,82] Elevated sacral skin temperature has previously been linked to an increased risk of PU development. The mean sacral skin temperature was > 35 °C, the Pus developed, while in those who did not develop PUs, it was < 34.0 °C.^[83] In addition, each 1 °C contributes 13.0 to 15.0 times as much to the damage score as one mmHg. The skin damage score rose at a rate of 0.078 (damage score/1 °C) in the temperature range of 33.5 °C to 37 °C, compared to 0.028 (damage score/1 °C) in the temperature range of 29.4 °C to 33.5 °C.^[84]

4. Limitations of the study

As a result, this research aimed to create frequently used air beds that control airflow in and out of the air mattress to aid in ventilation and air circulation for patients, hence reducing the occurrence of PUs. However, the first part of this research is to build the cooling system and determine the best conditions,

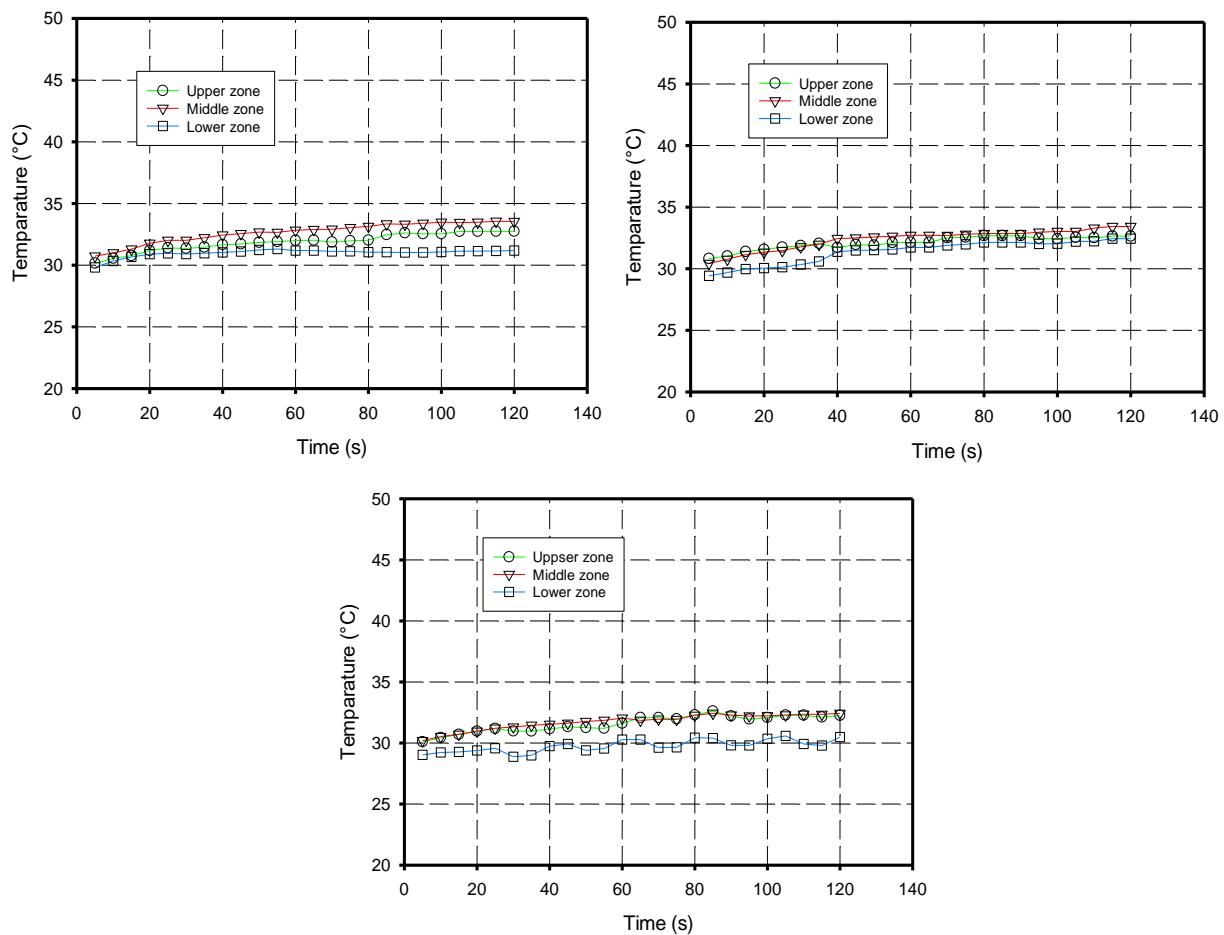


Fig. 12 shows the mattress temperature distribution with a thermoelectric air-cooling box (TACB) from three females.

which necessitates the installation of multiple sensors or equipment to monitor different parameters continuously. It is difficult to conduct tests on bedridden or elderly patients and disturb the rest of the bedridden or elderly patients. Therefore, the first research was conducted on healthy Thai students. However, suppose the cooling system's working conditions are suitable, including appropriate climate adjustment conditions. In that case, installing specific equipment or testing procedures may not be required as it has been thoroughly tested on bedridden patients or older people, which was a study limitation and will be the next step in future work.

In addition, participants were found sleeping in bed on their backs. People may prefer to sleep face down or on one side in reality; it is yet unknown how this will impact their thermal comfort while using a cooling system. This study's volunteers are healthy humans (five males and five females). People who are sleeping and those who are awake have distinct needs for thermal comfort. Volunteers in the trials included young men and women of varied heights, weights, and BMIs. Participants with varying age groups and physiological characteristics were not allowed to participate in the study. In addition, the environmental temperature significantly affects the mattress

temperature.

5. Conclusions

This work aims to present the design, manufacturing, and testing of a rubber mattress with a thermoelectric air-cooling box to minimize the occurrence of PUs in elderly and bedridden patients: a case study in Thailand. Given the small size of the equipment, low maintenance costs, and lack of mechanical parts, a thermoelectric air-cooling system is a unique option for cooling the mattress. It is found that the maximum temperature of the mattress occurs at the upper and middle zones. The maximum temperature of the mattress without the thermoelectric air-cooling system is 35-36 °C. With a thermoelectric air-cooling system, the maximum temperature of the mattress is decreased by about 3-5 °C. The thermoelectric air-cooling system significantly affects the thermal comfort zone control. In the future, mattresses with a thermoelectric air-cooling system will be used on the elderly and bedridden individuals. When treating pressure ulcers, a rubber mattress with a thermoelectric air-cooling system is one of the ways that produces better results than standard hospital beds.

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Conflict of Interest

There is no conflict of interest.

Supporting Information

Not applicable.

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