



US 20160066701A1

(19) **United States**

(12) **Patent Application Publication**
Diller et al.

(10) **Pub. No.: US 2016/0066701 A1**

(43) **Pub. Date: Mar. 10, 2016**

(54) **CONTROLLED CLIMATE BED WITH
SLEEPER FEEDBACK**

Publication Classification

(71) Applicants: **Board of Regents, The University of
Texas System**, Austin, TX (US);
Gentherm Incorporated, Northville, MI
(US)

(51) **Int. Cl.**
A47C 21/04 (2006.01)
(52) **U.S. Cl.**
CPC *A47C 21/048* (2013.01); *A47C 21/044*
(2013.01)

(72) Inventors: **Kenneth R. Diller**, Elgin, TX (US);
David Brian Marquette, Farmington
Hills, MI (US); **Michael Julius
Brykalski**, South Lyon, MI (US)

(57) **ABSTRACT**

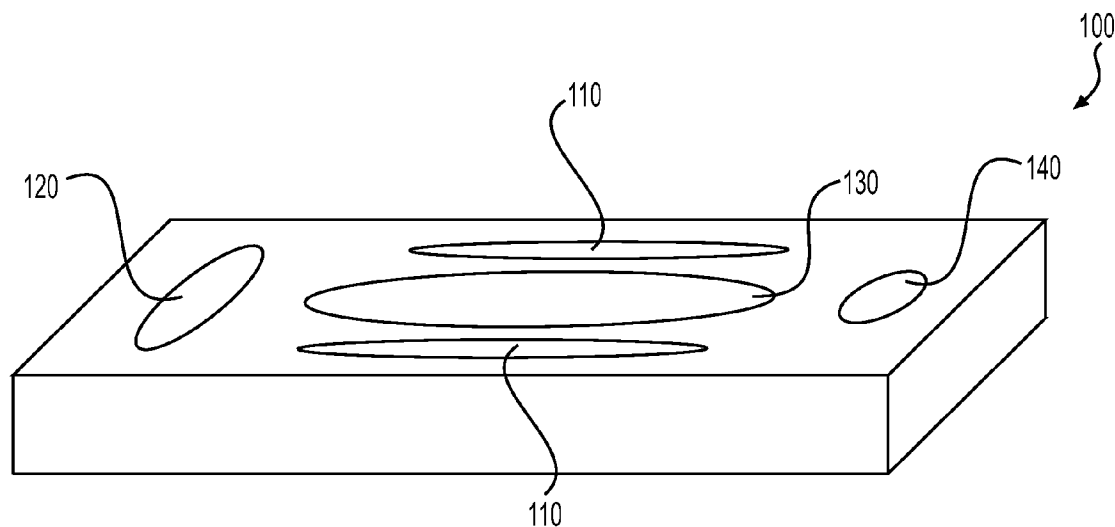
A climate-controlled bed capable of adapting to the needs of a sleeper via a closed loop feedback control system is provided. The bed includes a thermoelectric energy source, a sensor configured to monitor a physiological temperature of a sleeper, and a control system that regulates a temperature of the bed via the thermoelectric energy source. The control system can utilize data from the sensor to determine optimal thermal needs of the sleeper. The control system can also vary the temperature of the bed during a sleep cycle based on at least one predetermined sleep factor, such as the natural circadian temperature cycle.

(21) Appl. No.: **14/850,682**

(22) Filed: **Sep. 10, 2015**

Related U.S. Application Data

(60) Provisional application No. 62/048,528, filed on Sep. 10, 2014.



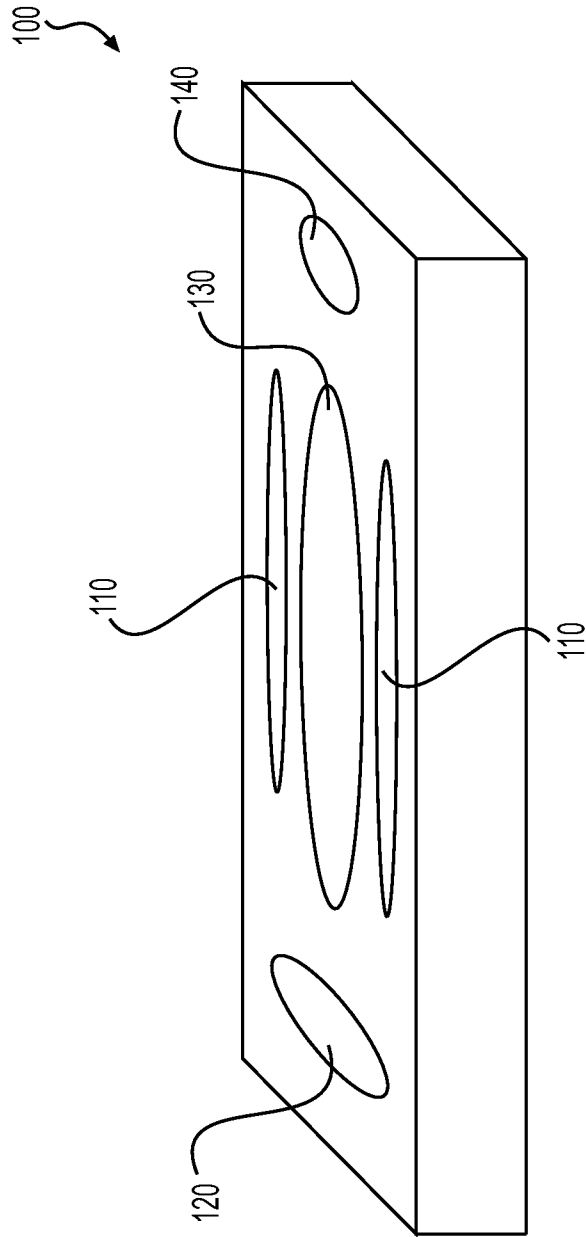


FIG. 1

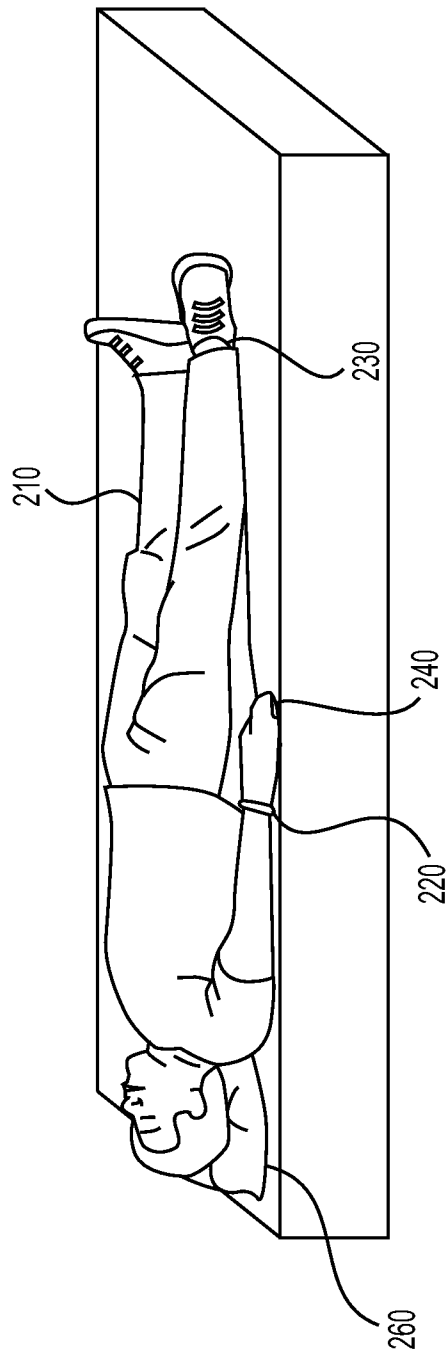


FIG. 2

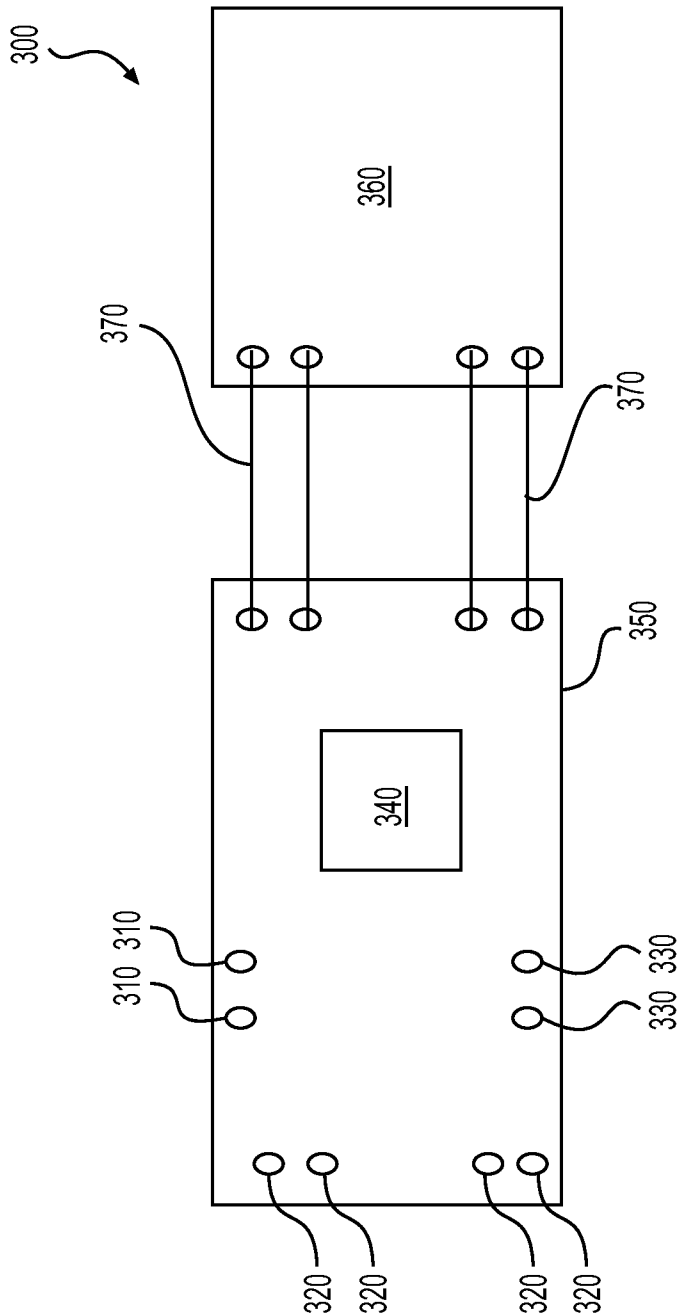


FIG. 3

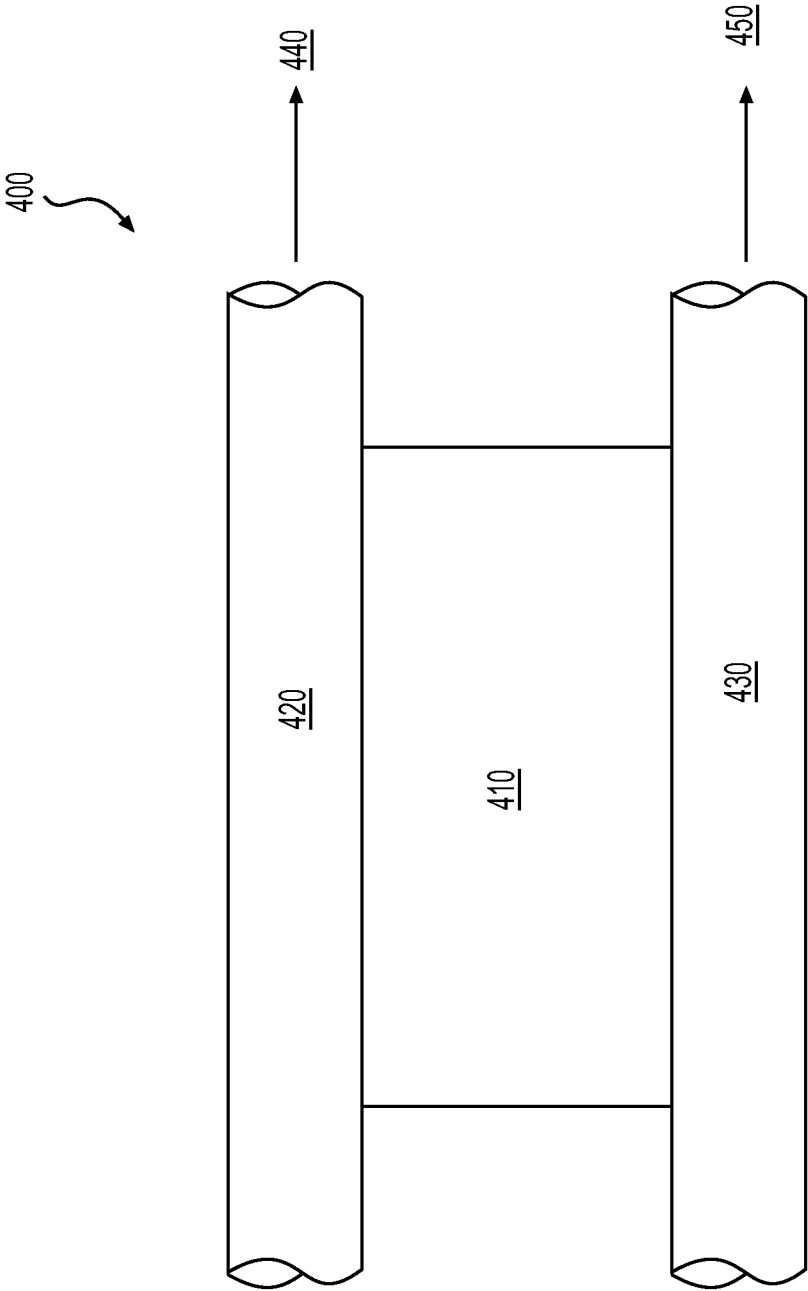


FIG. 4

CONTROLLED CLIMATE BED WITH SLEEPER FEEDBACK

PRIORITY

[0001] This application claims priority to U.S. Application No. 62/048,528, filed Sep. 10, 2014 and hereby incorporated herein in its entirety.

GOVERNMENT SUPPORT

[0002] This invention was made with government support under Grant No. CBET1250659 awarded by the National Science Foundation. The government has certain rights in the invention.

BACKGROUND

[0003] An important aspect of human comfort during sleep is thermal comfort. Empirical tools have been developed for determining air temperature and humidity that produce thermal comfort as a function of the level of physical activity, or metabolic rate, and insulating properties of the clothing that the person is wearing. Other research has documented that the human thermoregulatory system operates on a circadian cycle, much as does sleep, and that the thermoregulatory system is functionally involved in driving the sleep onset, continuation, and completion process.

[0004] For example, throughout the day a typical person will experience a relatively high body core temperature which peaks in the evening. As the body core temperature begins to drop, sleep onset occurs. The body core temperature continues to drop through the night. Prior to awakening in the morning, the process reverses and temperatures begin to rise, facilitating the completion of sleep. Much of the heat transfer that causes body core temperature changes occurs through glabrous skin, which in humans is skin that is naturally hairless, such as the skin found on the ventral portion of the fingers and toes, palmar surfaces of the hands, soles of feet, and other areas.

[0005] Modulation of blood flow to arteriovenous anastomoses (“AVAs”) in glabrous skin of the hands and feet—commonly referred to as “distal blood flow”—plays a major role in determining whether quality sleep occurs. For example, vasodilated AVAs, which are associated with warm feet, have been shown to promote rapid onset of sleep, whereas vasoconstricted AVAs produce delayed sleep onset. The AVAs in glabrous skin function as the primary heat transfer portals between the body core and the environment.

[0006] Recently, bed and mattress manufacturers have become increasingly aware of the effects of thermoregulation on sleep quality. For example, memory foam mattresses are well known to be highly insulating, resulting in sleepers becoming overheated part way through the sleep cycle and causing sleep difficulty associated with a higher body core temperature thereafter. This drawback has been difficult to overcome, with some manufacturers relying on passive solutions such as embedding phase-change pellets in the upper layers of the mattress to store body heat by melting rather than an increase in substrate temperature.

[0007] The current methods of thermal regulation have particular drawbacks. For example, influencing thermal regulation by way of air temperature is highly inefficient and generally ineffective. Passive solutions, such as the phase-change pellets described above, have a limited capacity for heat absorption before becoming useless to temperature regula-

tion. In addition, none of these methods take into account the changing temperature of the sleeper at different points in time during the sleep cycle. As a result, even if an ideal temperature can be achieved at one point during the sleep cycle, the sleeper's temperature may change to such an extent that the sleeper is unable to continue sleeping. Current systems and methods are unable to adapt to a sleeper in this type of situation. Additionally, current systems are not able to vary temperature based on, for example, the circadian temperature cycle that occurs during sleep.

[0008] As a result, there is a distinct need for a system and/or method capable of maintaining a climate-controlled sleeping environment for a user. In particular, there is a need for a system and/or method that can monitor the temperature of a sleeper and react accordingly in a manner most beneficial for sleep. In addition, there is a need for an energy-efficient way to maintain a climate-controlled sleeping environment in order to reduce energy usage. The integration of closed-loop physiological feedback from a sleeper to create a personalized local thermal environment that will match the sleep comfort needs of an individual marks a major advance in the field of sleep studies.

[0009] Other systems, methods, features and/or advantages will be or may become apparent to one with skill in the art upon examination of the following drawings and detailed description. It is intended that all such additional systems, methods, features and/or advantages be included within this description and be protected by the accompanying claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The following detailed description will be better understood when read in conjunction with the appended drawings, in which there is shown one or more of the multiple embodiments of the present invention. It should be understood, however, that the various embodiments of the present invention are not limited to the precise arrangements and instrumentalities shown in the drawings.

[0011] FIG. 1 is an example embodiment of a climate-controlled bed having multiple climate zones.

[0012] FIG. 2 is an example embodiment of a sleeper in a sleeping position.

[0013] FIG. 3 is an example embodiment of a control system.

[0014] FIG. 4 is an example embodiment of a thermoelectric energy source providing cooling and/or warming air.

DETAILED DESCRIPTION

[0015] A climate-controlled bed capable of adapting to the needs of a sleeper is provided. The bed includes a thermoelectric energy source, a sensor configured to monitor a physiological temperature of a sleeper, and a control system that regulates a temperature of the bed via the thermoelectric energy source. The control system can utilize data from the sensor to determine optimal thermal needs of the sleeper. The control system can also vary the temperature of the bed during a sleep cycle based on at least one predetermined sleep factor, such as the natural circadian temperature cycle.

[0016] FIG. 1 shows an example embodiment of a climate-controlled bed. Bed 100 is shown as having a plurality of climate zones. For example, side climate zones 110 are located along the sides of bed 100. Foot climate zone 120 is located toward the foot end of bed 100. Central climate zone 130 is located in the center of bed 100. Finally, cervical-spine

climate zone **140** is located near the head of the bed. In one example embodiment, side climate zones **110**, foot climate zone **120**, and cervical-spine climate zone **140** are used as warming zones. In this example embodiment, central climate zone **130** is used as a cooling zone.

[0017] In an example embodiment, a zone may be warmed or cooled via a thermoelectric energy source (not shown) to provide warming or cooling to these zones. Warming or cooling may be provided in any number of ways, including for example via air flow, other types of fluid flow, or electrical resistance. The thermoelectric energy source may be used to simultaneously provide warming and cooling capacity to different zones. Alternatively, a plurality of thermoelectric energy sources may be implemented in order to have a dedicated energy source for warming and cooling, respectively.

[0018] In the example above, side climate zones **110**, foot climate zone **120**, and cervical-spine climate zone **140** are designated as warming zones, while central zone **130** is designated as a cooling zone. This example setup may be useful for increasing blood flow throughout the body by, for example, warming the extremities of the body as well as the cervical spine to promote blood flow. The increased blood flow would facilitate cooling from the central zone **130**, as increased blood flow would lead to an increase in heat transfer from the sleeper to the bed.

[0019] In other example embodiments, more zones or fewer zones may be utilized by bed **100**. Additionally, each zone may be designated as a cooling or warming zone. In some embodiments, the temperature of each zone may be varied according to the needs of the user. For example, if the user is exceedingly cool when first getting onto bed **100**, all of the zones may be turned to their warming functions. As the user's temperature rises, the temperatures of the zones may be adjusted accordingly.

[0020] Monitoring the user may be done in a variety of ways. FIG. 2 shows an example embodiment of a user **210** in a sleeping position. The user is depicted as being fully clothed, but of course user **210** is likely to be dressed in appropriate sleep attire. In an example embodiment, user **210** is wearing a first sensor **220**. First sensor **220** is shown as being attached to the arm of user **210**, however the sensor may be placed in any other suitable location. Sensor **220** may measure a variety of physiological properties, including for example temperature, heart rate, blood pressure, and motion. Sensor **220** may be incorporated into a device such as a wrist band, forearm band, or the like.

[0021] FIG. 2. discloses additional sensors as well. For example, a leg sensor **230** is shown attached to the user near the ankle. Leg sensor **230** may be placed on the calf or ankle such that it contacts non-glabrous skin and provides a temperature measurement for that type of skin. An additional sensor may be located on glabrous skin in order to provide a temperature comparison between the user's glabrous and non-glabrous skin, which may be interpreted as an indication of the level of blood flow to glabrous skin and of the status of the thermoregulatory function, especially in relation to the circadian cycle. For example, glabrous sensor **240** may be placed on the hands or feet to measure the temperature of the glabrous skin at those locations. Additionally, a finger clip pulse oximeter may be incorporated into, for example, sensor **240** for use on the user's finger. Additional sensors may be incorporated at other locations of the user's body.

[0022] FIG. 2 also depicts a pillow **260**. In some embodiments, pillow **260** can function as an energy source providing

either warming or cooling energy. Pillow **260**, while shown in the form of a pillow, may also take the form of a heating/cooling blanket or pad or any other type of object or article that can be placed on the sleeping surface of the bed. Pillow **260** can be located in or comprise a climate zone, yet need not be in a particular location on the bed; rather, it may be located at any area of the bed that provides some sort of thermodynamic interaction with the sleeper. For example, pillow **260** may be placed next to the sleeper, abutting the sleeper's sides and/or arm.

[0023] The various sensors described above can be connected directly or wirelessly to a control system. FIG. 3 discloses control system **300**, which can include controller **350** and thermoelectric controller **360**. In an example embodiment, control system **300** is responsible for receiving inputs from all available sensors, determining which zones to heat/cool, and instructing the thermoelectric energy source to perform particular heating and/or cooling actions. In the example embodiment of FIG. 3, controller **350** is configured to receive power inputs **310**, temperature inputs **320**, and non-temperature physiological inputs **330**. Power inputs **310** may include, for example, a connector that plugs into a power outlet near the bed. Temperature inputs **320** include any temperature sensors on glabrous and/or non-glabrous skin of the user. Non-temperature physiological inputs **330** may include measurements of heart rate, blood pressure, oxygen levels, and so on. Other physiological inputs may be incorporated into the design as well. The particular number of input ports shown in FIG. 3 is not intended to be limiting—any number of sensors may be used.

[0024] In an example embodiment, controller **350** receives various inputs and determines, via a logic processor **340**, how to heat and/or cool various zones of bed **100**. For example, logic processor **340** may be capable of determining sleep onset based on information gathered from the user using predetermined sleep factors. Predetermined sleep factors include any factor relevant to the user's sleep. Examples include the circadian cycle of temperature variation, the time of day or night, the user's temperature on glabrous or non-glabrous skin sites, the user's heart rate, blood pressure, or blood oxygen levels, and so on. Logic processor **340** can be equipped with data regarding the natural circadian cycle of temperature variation. Using that data and comparing it to the data measured from the user, logic processor **340** can determine the appropriate method of facilitating sleep for the user. After determining a method of facilitating sleep, logic processor **340** causes controller **350** to communicate instructions to thermoelectric controller **360** via an electrical interface **370**. Thermoelectric controller **360** is capable of relaying instructions to the thermoelectric device itself, which provides heating or cooling as desired. The controller **350** may also be equipped with a data logging or recording function to retain information about a sleeper during sleep and may be recovered at a later time for analysis.

[0025] In another embodiment, control system **300** is capable of receiving inputs directly from the user. For example, if the user feels too cold to sleep, the user can indicate this to control system **300**, which will take appropriate measures based on a predetermined programmed response. Control system **300** may combine the inputs from a user with other factors to determine the optimal method of heating and/or cooling the bed.

[0026] FIG. 4 discloses a thermoelectric device **400** for use in the example embodiments described above, as well as other

embodiments. Thermoelectric device **400** is capable of providing warming and/or cooling capacity to different areas of the bed. In an example embodiment, thermoelectric device **400** includes an energy source **410**. Energy source **410** may use, for example, electrical energy in order to heat or cool a fluid. While FIG. 4 shows energy source **410** as a single device that provides both heating and cooling services, it may alternatively comprise two devices that are responsible for heating and cooling, respectively. In one embodiment, energy source **410** uses heat created by cooling a fluid in conjunction with the cooled fluid to simultaneously warm and cool different locations of the bed.

[0027] In an example embodiment, energy source **410** can be operatively connected to pipes that carry heated or cooled fluid to various areas of the bed. In the embodiment of FIG. 4, a cold-side air duct **420** and a warm-side air duct **430** is depicted. The cold-side air duct **420** is attached to energy source **410** such that a cooling air flow **440** is directed through cold-side air duct **420**. Cooling air flow **440** may be directed to multiple different zones of the bed depending on the needs of the user. The warm-side air duct **430** is attached to energy source **410** such that a warming air flow **450** is directed through warm-side air duct **430**. Warming air flow **450** may be directed to multiple different zones of the bed depending on the needs of the user. Cooling air flow **440** and warming air flow **450** may be sent to different areas of the bed simultaneously.

[0028] While specific embodiments have been described in detail in the foregoing detailed description and illustrated in the accompanying drawings, it will be appreciated by those skilled in the art that various modifications and alternatives to those details could be developed in light of the overall teachings of the disclosure and the broad inventive concepts thereof. It is understood, therefore, that the scope of the present disclosure is not limited to the particular examples and implementations disclosed herein, but is intended to cover modifications within the spirit and scope thereof as defined by the appended claims and any and all equivalents thereof.

What is claimed is:

1. A climate-controlled bed, comprising:
a first thermal energy source; and
a control system that regulates a temperature of the bed via the first thermal energy source,
wherein the control system varies the temperature during a sleep cycle of the user based on at least one predetermined sleep factor.
2. The bed of claim 1, further comprising a sensor configured to monitor a physiological temperature of a user, wherein the control system utilizes data from the sensor.
3. The bed of claim 1, wherein the control system is a closed-loop feedback system.
4. The bed of claim 1, wherein the sleep factors comprise at least one of the natural circadian cycle of temperature variation, the local time, and the user's current temperature.
5. The bed of claim 1, further comprising a second sensor configured to monitor at least a heart rate, physical movement, sweating, blood pressure, or a thermal state of the user.

6. The bed of claim 1, wherein the first thermal energy source simultaneously provides cooling and warming to separate air streams directed to different areas of the bed sleeping surface.

7. The bed of claim 1, further comprising a cooling source configured to decrease the temperature of at least a portion of the bed.

8. The bed of claim 1, further comprising a second thermal energy source disposed on the bed.

9. The bed of claim 1, wherein the control system varies the temperature via heating at least a portion of an article disposed on the bed.

10. The bed of claim 9, wherein the article is one of a pillow and a heating pad.

11. A system for controlling the climate of a bed having a plurality of zones, comprising:

an energy source; and

a control system that can regulate temperatures of each zone of the bed via the energy source.

12. The system of claim 11, further comprising a sensor configured to monitor a physiological temperature of a user.

13. The system of claim 11, further comprising a plurality of sensors, each configured to monitor a physiological temperature of the user at a different location.

14. The system of claim 11, further comprising a cooling source configured to decrease the temperature of at least one zone of the bed.

15. The system of claim 14, wherein heating and cooling may be applied to different zones of the bed simultaneously.

16. The system of claim 11, wherein the control system may be customized to match particular needs of the user.

17. The system of claim 11, wherein the energy source is disposed on the bed.

18. A method of controlling temperatures of a bed, comprising

providing an energy source;

monitoring temperature data of a user via a control system;

modifying the temperature of the bed, via the energy source, based on the user's temperature data compared to a target temperature customized to the user.

19. The method of claim 18, wherein monitoring the temperature of the user comprises placing sensors on at least one glabrous skin site and optionally on at least one non-glabrous skin site.

20. The method of claim 18, further comprising monitoring at least one of heart rate, physical movement, and sweating of the user.

21. The method of claim 18, wherein the ideal temperature customized to the user is based on data representing a natural circadian cycle of temperature variation.

22. The method of claim 18, wherein the ideal temperature customized to the user is based on a request by the user.

23. The method of claim 18, wherein the energy source is provided on the bed.

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