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System and method of harvesting wireless energy for climate control in a vehicle

Abstract

Systems and methods of harvesting wireless energy for climate control in a cabin of a vehicle are provided. The method comprises receiving an electromagnetic (EM) signal of EM radiation having EM energy to define an EM current. The method further comprises filtering the EM energy to regulate the EM current converting the EM current to direct current. The method further comprises storing the direct current for powering a battery-free wireless sensing unit and powering the battery-free wireless sensing unit with the direct current. After powering the battery-free wireless sensing unit, the method comprises sensing an actual condition in the cabin, the actual condition being one of actual temperature and actual humidity in the cabin. Furthermore, the method comprises adjusting one of temperature and humidity in the cabin in response to a difference between the actual condition and a set condition.

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Background/Summary

INTRODUCTION

- (1) The present disclosure relates to climate control sensor units and, more particularly, climate control sensor units for harvesting wireless energy and controlling climate in a cabin of a vehicle.
- (2) Climate control is common and needed in a cabin of a vehicle. However, deploying wired or battery-based sensor units can be complex and cumbersome.

SUMMARY

- (3) Thus, while current climate control units achieve their intended purpose, there is a need for a new and improved climate control unit and a method of harvesting wireless energy for climate control in a cabin of a vehicle.
- (4) In accordance with one aspect of the present disclosure, a battery-free wireless climate control unit for harvesting wireless energy and for controlling climate in a cabin of a vehicle is provided. The climate control unit comprises an antenna having a transceiver arranged to receive an electromagnetic (EM) signal of EM radiation having EM energy to define an EM current. In this aspect, the climate control unit further comprises a wireless energy harvesting (WEH) unit in communication with the antenna. The WEH unit is arranged to filter the EM energy to regulate or

resist the EM current. Moreover, the WEH unit is arranged to convert the EM current to direct current.

(5) Further to this aspect, the climate control unit comprises a power management (PM) unit in communication with the WEH unit. The PM unit is arranged to store the direct current and arranged to distribute the direct current. Moreover, the climate control unit further comprises a sensor in communication with the PM unit. In this aspect, the sensor is arranged to receive the direct current from the PM unit for power. Additionally, the sensor is arranged to sense an actual condition being one of temperature and humidity in the cabin. Further, the sensor is arranged to transmit a cabin signal of the actual condition.

(6) Furthermore, the climate control unit further comprises a controller in communication with the sensor and the PM unit. In this aspect, the controller is arranged to receive the direct current from the PM unit for power. Moreover, the controller is arranged to receive the cabin signal of the actual condition from the sensor. Additionally, the controller is arranged to adjust one of temperature and humidity in the cabin in response to a difference between the actual condition and a set condition. In this aspect, the set condition is one of a preset temperature and a preset humidity in the cabin.

(7) In one embodiment, the sensor is arranged to sense a plurality of actual conditions across a plurality of locations in the cabin. In this embodiment, the controller is arranged to create a heat map of the cabin from at least a portion of the plurality of actual conditions by way of an interpolation technique with respect to time and area of the cabin. Additionally, the controller is arranged to adjust one of temperature and humidity in the cabin with the interpolation technique in response to a difference between the plurality of the actual conditions and a corresponding plurality of the set conditions with the area of the cabin.

(8) In another embodiment of this aspect, the sensor is arranged to sense an outside condition being one of temperature and humidity outside of the vehicle. Moreover, the sensor is arranged to transmit an outside signal of the outside condition. In this embodiment, the controller is arranged to receive the outside signal of the outside condition from the sensor. Additionally, the controller is arranged to adjust one of temperature and humidity in the cabin in response to the outside signal and the difference between the actual condition and the set condition.

(9) In yet another embodiment, the antenna extends from the sensor for at least 5 centimeters (cm). In still another embodiment, the sensor has a response time of at least 1 millisecond (ms).

(10) In accordance with another aspect of the present disclosure, a method of harvesting wireless energy for climate control in a cabin of a vehicle is provided. The method comprises providing a battery-free wireless sensing unit for a climate control unit of the vehicle and receiving an electromagnetic (EM) signal of EM radiation having EM energy to define an EM current. The method further comprises filtering the EM energy to regulate the EM current and, after filtering, converting the EM current to direct current.

(11) In this aspect, the method further comprises storing the direct current for powering the battery-free wireless sensing unit and powering the battery-free wireless sensing unit with the direct current. After powering the battery-free wireless sensing unit, the method further comprises sensing an actual condition in the cabin. The actual condition is one of actual temperature and actual humidity in the cabin.

(12) Furthermore, the method comprises adjusting one of temperature and humidity in the cabin in response to a difference between the actual condition and a set condition. The set condition is one of a preset temperature and a preset humidity in the cabin.

(13) In one example, sensing the actual condition in the cabin comprises sensing a plurality of actual conditions across a plurality of locations in the cabin. In this example, adjusting one of temperature and humidity in the cabin comprises creating a heat map of the cabin from at least a portion of the plurality of actual conditions by way of an interpolation technique with respect to time and area of the cabin. In this example, adjusting one of temperature and humidity in the cabin further comprises adjusting one of temperature and humidity in the cabin with the interpolation

technique in response to a difference between the plurality of the actual conditions and a corresponding plurality of the set conditions with the area of the cabin.

(14) In another example, sensing the actual condition in the cabin comprises sensing an outside condition being one of temperature and humidity outside the vehicle. In this example, adjusting one of temperature and humidity in the cabin comprises adjusting one of temperature and humidity in the cabin in response to the outside condition and the difference between the actual condition and the set condition.

(15) In accordance with yet another aspect of the present disclosure, a system for harvesting wireless energy for climate control in a cabin of a vehicle is provided. The system comprises a heating, ventilation, and cooling (HVAC) unit disposed in the vehicle for heating, venting, and cooling the cabin of the vehicle.

(16) In this aspect, the system further comprises a climate control unit in communication with the HVAC unit. The climate control unit comprises an antenna having a transceiver arranged to receive an electromagnetic (EM) signal of EM radiation having EM energy to define an EM current. The climate control unit further comprises a wireless energy harvesting (WEH) unit in communication with the antenna. In this aspect, the WEH unit is arranged to filter the EM energy to regulate the EM current. Moreover, the WEH unit is arranged to convert the EM current to direct current.

(17) In accordance with this aspect, the climate control unit further comprises a power management (PM) unit in communication with the WEH unit. The PM unit is arranged to store the direct current. Additionally, the PM unit is arranged to distribute the direct current.

(18) Moreover, the climate control unit comprises a sensor in communication with the PM unit. In this aspect, the sensor is arranged to receive the direct current from the PM unit for power. Moreover, the sensor is arranged to sense an actual condition being one of temperature and humidity in the cabin. Further, the sensor is arranged to transmit a cabin signal of the actual condition.

(19) In this aspect, the climate control unit comprises a controller in communication with the sensor and the PM unit. The controller is arranged to receive the direct current from the PM unit for power. Moreover, the controller is arranged to receive the cabin signal of the actual condition from the sensor. Furthermore, the controller is arranged to activate the HVAC unit to adjust one of temperature and humidity in the cabin in response to a difference between the actual condition and a set condition. The set condition is one of a preset temperature and a preset humidity in the cabin.

(20) In one embodiment, the sensor is arranged to sense a plurality of actual conditions across a plurality of locations in the cabin. In this embodiment, the controller is arranged to create a heat map of the cabin from at least a portion of the plurality of actual conditions by way of an interpolation technique with respect to time and area of the cabin. Moreover, the controller is arranged to adjust one of temperature and humidity in the cabin with the interpolation technique in response to a difference between the plurality of the actual conditions and a corresponding plurality of the set conditions with the area of the cabin.

(21) In another embodiment of this aspect, the sensor is arranged to sense an outside condition being one of temperature and humidity outside of the vehicle. In addition, the sensor is arranged to transmit an outside signal of the outside condition. Further to this embodiment, the controller is arranged to receive the outside signal of the outside condition from the sensor. Additionally, the controller is arranged to adjust one of temperature and humidity in the cabin in response to the outside signal and the difference between the actual condition and the set condition.

(22) In yet another embodiment, the antenna extends from the sensor for at least 50 cm. In still another embodiment, the sensor has a response time of between 5 ms and 600 ms.

(23) Further areas of applicability will become apparent from the description provided herein. It should be understood that the description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

- (1) The drawings described herein are for illustration purposes only and are not intended to limit the scope of the present disclosure in any way.
- (2) FIG. 1 is a perspective view in a cabin of a vehicle having a battery-free wireless climate control unit for harvesting wireless energy in accordance with one embodiment of the present disclosure.
- (3) FIG. 2 is a schematic view of the battery-free wireless climate control unit in FIG. 1.
- (4) FIG. 3 is a heat map graph of space vs. time of the cabin for climate control.
- (5) FIG. 4A is a schematic diagram of a general system in the vehicle of FIG. 1 having the climate control unit for harvesting wireless energy.
- (6) FIG. 4B is a schematic diagram of a system for harvesting wireless energy for climate control in the vehicle of FIG. 1 in accordance with one embodiment of the present disclosure
- (7) FIG. 5 is a flowchart of a method of harvesting wireless energy for climate control in the vehicle of FIG. 1 in accordance with one example of the present disclosure.

DETAILED DESCRIPTION

- (8) The following description is merely exemplary in nature and is not intended to limit the present disclosure, application, or uses.
- (9) Embodiments and examples of the present disclosure provide a battery-free wireless climate control unit, and systems and methods of harvesting wireless energy for climate control in a cabin of a vehicle. Such embodiments and examples reduce deployment complexity and provide an more cost-saving way to control climate in a cabin of a vehicle.
- (10) FIG. 1 illustrates a cabin **10** of a vehicle **12** having battery-free wireless climate control units **14** for harvesting wireless energy and for controlling climate therein in accordance with one embodiment of the present disclosure. As shown, the climate control units **14** are disposed in the cabin **10** of the vehicle **12**. Preferably, the climate control units **14** may be disposed in a seat cushion, a head rest, an interior panel, a floorboard, or a ceiling board in the cabin of the vehicle. However, it is understood that the climate control unit **14** may be disposed in any other suitable location in the vehicle without departing from the spirit or scope of the present invention.
- (11) Referring to FIGS. 1-2, the climate control unit **14** comprises an antenna **20** having a transceiver **21** arranged to receive an electromagnetic (EM) signal of EM radiation having EM energy to define an EM current. In this embodiment, the EM signal is a radio frequency (RF) signal carrying both data and energy by way of an RF identification (RFID) protocol. However, it is to be understood that the EM signal may be any other suitable EM signal by way of any other suitable protocol or network such as Bluetooth low energy (BLE), wireless fidelity (WiFi), long-term evolution (LTE), or internet of things (IoT) without departing from the spirit or scope of the present disclosure.
- (12) As depicted in FIG. 2, the climate control unit **14** further comprises a wireless energy harvesting (WEH) unit **22** in communication with the antenna **20**. From the antenna **20**, the WEH unit **22** receives the EM signal and stores the EM energy thereof. In one embodiment, the WEH unit **22** may comprise a capacitor (not shown) arranged to store EM energy of the EM signal. Moreover, the WEH unit **22** is arranged to filter the EM energy to regulate or resist the EM current. For example, the WEH unit **22** may comprise an inducer (not shown) arranged to filter the EM energy for regulating or resisting the EM current. Moreover, the WEH unit **22** is arranged to convert the EM current to direct current. As an example, the WEH unit **22** may comprise a rectifier (not shown) arranged to convert the EM current (here, RF current) to direct current (DC) to be used for powering devices and charging batteries as discussed below. Other components may be used in replacement or in addition to the components of the WEH unit **22** without departing from the spirit

or scope of the present disclosure.

(13) As depicted in FIG. 2, the climate control unit **14** further comprises a power management (PM) unit **24** in communication with the WEH unit **22**. The PM unit **24** receives the direct current from the WEH unit **22**. In this embodiment, the PM unit **24** is arranged to store the direct current to a desired or required DC output power/electrical potential to power devices (discussed below). Additionally, the PM unit **24** is arranged to distribute the direct current. In one example, the PM unit **24** may comprise a storage capacitor (not shown) to store the direct current and a DC-DC converter (not shown) to convert the direct current to a required DC output power. In this embodiment, the PM unit **24** may also comprise an electronic control module arranged to manage a distribution of available energy across a plurality of consuming devices to maximize lifetime of the devices while maintaining efficiency. Other components may be used in replacement or in addition to the components of the PM unit **24** without departing from the spirit or scope of the present disclosure.

(14) Referring to FIG. 2, the climate control unit **14** further comprises a sensor **30** in communication with the PM unit **24** and the antenna **20**. In this embodiment, the sensor **30** may be a receiver/transmitter (or transceiver) arranged to receive and transmit signals of a consistent/backscatter protocol (here, RFID) or differing protocols (e.g., BLE, WiFi, LTE, or IoT). Moreover, the sensor **30** is arranged to receive the direct current from the PM unit **24** for power. Furthermore, in one embodiment, the antenna **20** preferably extends from the sensor **30** for a length of at least 50 centimeters (cm).

(15) Upon being powered, the sensor **30** is arranged to sense an actual condition in the cabin **10**. That is, the sensor **30** is disposed in an area of the cabin **10** (e.g., a head rest) and is arranged to sense, preferably continually sense, the actual condition of an area adjacent or proximate to the head rest. Preferably, the actual condition is temperature or humidity in the cabin **10**. Upon sensing the actual condition, the sensor **30** is arranged to transmit a cabin signal of the actual condition. It is to be understood that the sensor **30** may have a varied response time based on obstructions to the sensor **30** and a location at which the sensor **30** is disposed. Relative to the sensor **30**, the varied response time may be defined as a time between being powered and transmitting the cabin signal. For example, the sensor **30** may have a response time of between 5 milliseconds (ms) and 600 ms.

(16) As shown in FIG. 1, a plurality of climate control units **14** is preferably disposed throughout the cabin **10** of the vehicle **12** and thereby the climate control units **14** (via the sensors **30**) are arranged to sense a plurality of actual conditions across a plurality of locations in the cabin **10**. The sensors **30** are arranged to continually sense the actual conditions over a timeframe. As such in this example, each sensor **30** is arranged to continually transmit cabin signals of the actual condition at a respective location in the cabin **10** over the timeframe. As a result, a plurality of cabin signals is continually transmitted for the actual condition at each location over the timeframe.

(17) Furthermore, the climate control unit **14** comprises a controller **32** in communication with the antenna **20**, the sensor **30**, and the PM unit **24**. In this embodiment, the controller **32** is arranged to receive the direct current from the PM unit **24** for power. Upon being powered, the controller **32** is arranged to receive the cabin signal of the actual condition from the sensor **30**. Based on the actual condition, the controller **32** is arranged to adjust one of temperature and humidity in the cabin **10** in response to a difference between the actual condition and a set condition. In this embodiment, the set condition is one of a preset temperature and a preset humidity in the cabin **10**. That is, the controller **32** is arranged to store the set condition (e.g., 70F) and compare the actual condition (e.g., 65F) with the set condition. The controller **32** is arranged to adjust the temperature, for example, in the cabin **10** based on the difference.

(18) It is to be understood that the controller **32** may implement algorithms and modules to assist in comparisons and calculations relative to climate control of the cabin **10**. It is also to be understood that the controller **32** may be an electronic control unit (ECU), a body control module (BCM), or any other suitable control device without departing from the spirit or scope of the present

disclosure.

(19) As depicted in FIG. 1, a plurality of climate control units **14** is preferably disposed throughout the cabin **10** of the vehicle **12** and thereby the climate control units **14** are arranged to sense a plurality of actual conditions across a plurality of locations in the cabin **10**. Thus, the controller **32** may receive the plurality cabin **10** signals of actual conditions from the sensors **30** across the plurality of locations in the cabin **10**.

(20) FIG. 3 depicts a heat map graph **110** of space vs. time of climate in the cabin **10**. With respect to the response time, the controller **32** is arranged to create a heat map **112** of the cabin **10** from at least a portion of the plurality of actual conditions **114** by way of an interpolation technique providing estimated or interpolated conditions **116** of temperature or humidity. The estimated conditions **116** may be implemented by the controller **32** for more accurate and efficient climate control in the cabin **10**. In this embodiment, the interpolation technique is performed with respect to area in the cabin (x-axis), time (y-axis), and actual conditions (z-axis). Moreover, since the plurality of cabin signals received may be sparse due to the response time of each sensor **30**, the controller **32** may be arranged to create the heat map **112** from sparse measurements of the cabin **10** to assist with controlling climate in the cabin **10**.

(21) In this embodiment and without departing from the spirit or scope of the present disclosure, the interpolation technique may be a global technique to interpolate values using all available data, a local technique to estimate values from neighboring points only, or any other suitable technique to assist in creating the heat map for climate control of the cabin **10**. Furthermore, the controller **32** may implement the interpolation technique by way of algorithms and modules.

(22) Referring back to FIG. 2, the controller **32** is arranged to adjust one of temperature and humidity in the cabin **10** with the interpolation technique in response to a difference between the plurality of the actual conditions and a corresponding plurality of the set conditions with the area of the cabin **10**. It is to be understood that the controller **32** may implement algorithms and modules to assist in comparisons and calculations relative to climate control of the cabin **10**.

(23) In one embodiment, the sensor **30** may be arranged to sense an outside condition being one of temperature and humidity outside of the vehicle **12**. As such, the sensor **30** may be arranged to transmit an outside signal of the outside condition. In this example, the controller **32** is arranged to receive the outside signal of the outside condition from the sensor **30**. Moreover, the controller **32** is arranged to adjust one of temperature and humidity in the cabin **10** in response to the outside signal and the difference between the actual condition and the set condition.

(24) FIGS. 4A-4B depict a system **210** for harvesting wireless energy for climate control in a cabin **10** of a vehicle **12** in accordance with another embodiment of the present disclosure. As shown, the system **210** implements the climate control unit **14** described above and depicted in FIGS. 1 and 2. Additionally, the system **210** comprises a heating, ventilation, and cooling (HVAC) unit **212** disposed in the vehicle **12** for heating, venting, and cooling the cabin **10** of the vehicle **12**. The HVAC unit **212** may comprise an HVAC transceiver **213**, an air conditioning (A/C) unit **214** connected to the transceiver, a heating unit **216** connected to the A/C unit **214** and the HVAC transceiver **213**, and flap controls/activators **218** connect to each of the heating and A/C units **212**, **214**. Moreover, the system **210** comprises a human machine interface (HMI) unit **220** disposed in the vehicle **12** for driver/occupant interaction. The HMI unit **220** may comprise a HMI transceiver **221**, a user input component **222** in connection with the transceiver and a screen output component **224** connected to the HMI transceiver **221**. Other components may be used in replacement or in addition to the components of the HVAC unit **212** and the HMI unit **220** without departing from the spirit or scope of the present disclosure.

(25) As illustrated in FIGS. 4A-4B, the system **210** further comprises a battery-free wireless climate control unit **14** for harvesting wireless energy and for controlling climate in the cabin **10** of the vehicle **12** in accordance with one embodiment of the present disclosure. As shown in FIG. 4A, the climate control unit **14** is in communication with the HVAC unit **212** and the HMI unit **220**. In

this embodiment, the climate control unit **14** of the system **210** is preferably the climate control unit **14** shown in FIGS. 1-2 and described above.

(26) Referring to FIG. 4B, each climate control unit **14** is disposed in the cabin **10** of the vehicle **12**. Preferably, the climate control unit **14** may be disposed in a seat cushion, a head rest, an interior panel, a floorboard, or a ceiling board in the cabin **10** of the vehicle **12**. However, it is understood that the climate control unit **14** may be disposed in any other suitable location in the vehicle without departing from the spirit or scope of the present invention.

(27) Referring to FIGS. 2 and 4B, the climate control unit **14** comprises an antenna **20** having a transceiver **21** arranged to receive an electromagnetic (EM) signal of EM radiation having EM energy to define an EM current. In this embodiment, the EM signal is a radio frequency (RF) signal carrying both data and energy by way of an RF identification (RFID) protocol. However, it is to be understood that the EM signal may be any other suitable EM signal by way of any other suitable protocol or network such as Bluetooth low energy (BLE), wireless fidelity (WiFi), long-term evolution (LTE), or internet of things (IOT) without departing from the spirit or scope of the present disclosure.

(28) As depicted in FIGS. 2 and 4B, the climate control unit **14** further comprises a wireless energy harvesting (WEH) unit **22** in communication with the antenna **20**. From the antenna **20**, the WEH unit **22** receives the EM signal and stores the EM energy thereof. In one embodiment, the WEH unit **22** may comprise a capacitor (not shown) arranged to store EM energy of the EM signal. Moreover, the WEH unit **22** is arranged to filter the EM energy to regulate or resist the EM current. For example, the WEH unit **22** may comprise an inducer (not shown) arranged to filter the EM energy for regulating or resisting the EM current. Moreover, the WEH unit **22** is arranged to convert the EM current to direct current. As an example, the WEH unit **22** may comprise a rectifier (not shown) arranged to convert the EM current (here, RF current) to direct current (DC) to be used for powering devices and charging batteries as discussed below. Other components may be used in replacement or in addition to the components of the WEH unit **22** without departing from the spirit or scope of the present disclosure.

(29) As depicted in FIGS. 2 and 4B, the climate control unit **14** further comprises a power management (PM) unit **24** in communication with the WEH unit **22**. The PM unit **24** receives the direct current from the WEH unit **22**. In this embodiment, the PM unit **24** is arranged to store the direct current to a desired or required DC output power/electrical potential to power devices (discussed below). Additionally, the PM unit **24** is arranged to distribute the direct current. In one example, the PM unit **24** may comprise a storage capacitor (not shown) to store the direct current and a DC-DC converter (not shown) to convert the direct current to a required DC output power. In this embodiment, the PM unit **24** may also comprise an electronic control module arranged to manage a distribution of available energy across a plurality of consuming devices to maximize lifetime of the devices and while maintaining efficiency. Other components may be used in replacement or in addition to the components of the PM unit **24** without departing from the spirit or scope of the present disclosure.

(30) Referring to FIGS. 2 and 4B, the climate control unit **14** further comprises a sensor **30** in communication with the PM unit **24** and the antenna **20**. In this embodiment, the sensor **30** may be a receiver/transmitter (or transceiver) arranged to receive and transmit signals of a consistent/backscatter protocol (here, RFID) or differing protocols (e.g., BLE, WiFi, LTE, or IoT). Moreover, the sensor **30** is arranged to receive the direct current from the PM unit **24** for power. Furthermore, in one embodiment, the antenna **20** preferably extends from the sensor **30** for a length of at least 50 centimeters (cm).

(31) Upon being powered, the sensor **30** is arranged to sense an actual condition in the cabin **10**. That is, the sensor **30** is disposed in an area of the cabin **10** (e.g., a head rest) and is arranged to sense, preferably continually sense, the actual condition of an area adjacent or proximate to the head rest. Preferably, the actual condition is temperature or humidity in the cabin **10**. Upon sensing

the actual condition, the sensor **30** is arranged to transmit a cabin signal of the actual condition. It is to be understood that the sensor **30** may have a varied response time based on a location at which the sensor **30** is disposed and obstructions to the sensor **30**. Relative to the sensor **30**, the varied response time may be defined as a time between being powered and transmitting the cabin signal. For example, the sensor **30** may have a response time of between 5 milliseconds (ms) and 600 ms.

(32) Referring to FIGS. **1** and **4B**, a plurality of climate control units **14** is preferably disposed throughout the cabin **10** of the vehicle **12** and thereby the climate control units **14** (via the sensors **30**) are arranged to sense a plurality of actual conditions across a plurality of locations in the cabin **10**. The sensors **30** are arranged to continually sense the actual conditions over a timeframe. As such in this example, each sensor **30** is arranged to continually transmit cabin signals of the actual condition at a respective location in the cabin **10** over the timeframe. As a result, a plurality of cabin signals is continually transmitted for the actual condition of each location over the timeframe.

(33) Furthermore, referring to FIGS. **2** and **4B**, the climate control unit **14** comprises a controller **32** in communication with the antenna **20**, the sensor **30**, and the PM unit **24**. In this embodiment, the controller **32** is arranged to receive the direct current from the PM unit **24** for power. Upon being powered, the controller **32** is arranged to receive the cabin signal of the actual condition from the sensor **30**.

(34) Based on the actual condition, the controller **32** is arranged to activate the HVAC unit **212** (FIG. **4A**) to adjust one of temperature and humidity in the cabin **10** in response to a difference between the actual condition and a set condition. In operation, the controller **32** (via a transceiver or a current driver) may send a drive signal to the HVAC unit **212** which may activate flap controls and activators **218** to thereby provide heating or cooling to the cabin **10** accordingly. In this embodiment, the set condition is one of a preset temperature and a preset humidity in the cabin **10**. That is, the set condition may be preset by an occupant via the HMI unit **220** (FIG. **4A**). Further, the controller **32** may be arranged to store the set condition (e.g., **70F**) and compare the actual condition (e.g., **65F**) with the set condition.

(35) It is to be understood that the controller **32** may implement algorithms and modules to assist in comparisons and calculations relative to climate control of the cabin **10**. It is also to be understood that the controller **32** may be an electronic control unit (ECU), a body control module (BCM), or any other suitable control device without departing from the spirit or scope of the present disclosure.

(36) As depicted in FIGS. **1** and **4B**, a plurality of climate control units **14** is preferably disposed throughout the cabin **10** of the vehicle **12** and thereby the climate control units **14** are arranged to sense a plurality of actual conditions across a plurality of locations in the cabin **10**. Thus, the controller **32** may receive the plurality of cabin signals of the actual conditions from the sensors **30** across the plurality of locations in the cabin **10**.

(37) Referring to FIGS. **3** and **4A**, with respect to the response time, the controller **32** is arranged to create the heat map graph **110** comprising the heat map **112** of the cabin **10** from at least a portion of the plurality of actual conditions **114** by way of an interpolation technique to provide estimated or interpolated conditions **116**. The controller **32** uses the estimated conditions **116** to more effectively and efficiently control climate in the cabin **10**. In this embodiment, the interpolation technique is performed with respect to area in the cabin (x-axis), time (y-axis), and actual conditions in the cabin (z-axis). Moreover, since the plurality of cabin signals received may be sparse due to the response time of each sensor **30**, the controller **32** may be arranged to create the heat map **112** from sparse measurements of the cabin **10** to assist with controlling climate in the cabin **10**.

(38) In this embodiment and without departing from the spirit or scope of the present disclosure, the interpolation technique may be a global technique to interpolate values using all available data, a local technique to estimate values from neighboring points only, or any other suitable technique to assist in creating the heat map for climate control of the cabin **10**. Furthermore, the controller **32**

may implement the interpolation technique by way of algorithms and modules.

(39) Referring back to FIGS. 4A and 4B, the controller 32 is arranged to activate the HVAC unit 212 to adjust one of temperature and humidity in the cabin 10 with the interpolation technique in response to a difference between the plurality of the actual conditions and a corresponding plurality of the set conditions with the area of the cabin 10. It is to be understood that the controller 32 may implement algorithms and modules to assist in comparisons and calculations relative to climate control of the cabin 10. In operation, the controller 32 (via a transceiver or a current driver) may send a drive signal to the HVAC unit 212 which may activate flap controls and activators 218 to thereby provide heating or cooling to the cabin 10 accordingly.

(40) FIG. 5 illustrates a flowchart of a method of harvesting wireless energy for climate control in a cabin 10 of a vehicle 12. In this example, the method implements the system 210 and climate control unit 14 described above and shown in FIGS. 1, 2, 4A and 4B. As shown in block 312, the method comprises providing the HVAC unit 212, the HMI unit 220, and the climate control unit 14 described herein. As discussed above, the climate control unit 14 comprises the antenna 20, the WEH unit 22, the PM unit 24, the sensor 30, and the controller 32.

(41) In block 314, the method further comprises (via the antenna 20) receiving an electromagnetic (EM) signal of EM radiation having EM energy to define an EM current. In this example, the EM signal is a radio frequency (RF) signal carrying both data and energy by way of an RF identification (RFID) protocol. However, it is to be understood that the EM signal may be any other suitable EM signal by way of any other suitable protocol or network such as Bluetooth low energy (BLE), wireless fidelity (WiFi), long-term evolution (LTE), or internet of things (IOT) without departing from the spirit or scope of the present disclosure.

(42) In block 316, the method further comprises (via the WEH unit 22) filtering the EM energy to regulate the EM current. Moreover, in block 318, the method further comprises (via the WEH unit 22), after filtering, converting the EM current to direct current. From the antenna 20, the WEH unit 22 receives the EM signal and stores the EM energy thereof. In one embodiment, the WEH unit 22 may comprise a capacitor arranged to store EM energy of the EM signal. Moreover, the WEH unit 22 is arranged to filter the EM energy to regulate or resist the EM current. For example, the WEH unit 22 may comprise an inducer arranged to filter the EM energy for regulating or resisting the EM current. Moreover, the WEH unit 22 is arranged to convert the EM current to direct current. As an example, the WEH unit 22 may comprise a rectifier (not shown) arranged to convert the EM current (here, RF current) to direct current (DC) to be used for powering devices and charging batteries as discussed below. Other components may be used in replacement or in addition to the components of the WEH unit 22 without departing from the spirit or scope of the present disclosure.

(43) In block 320, the method further comprises (via the PM unit 24) storing the direct current for powering the battery-free wireless sensing unit. In block 322, the method comprises (via the PM unit 24) powering the battery-free wireless sensor 30 with the direct current. In operation, the PM unit 24 receives the direct current from the WEH unit 22. In this example, the PM unit 24 is arranged to store the direct current to a desired or required DC output power/electrical potential to power devices such as the sensor 30 and controller 32. Additionally, the PM unit 24 is arranged to distribute the direct current. In one example, the PM unit 24 may comprise a storage capacitor to store the direct current and a DC-DC converter to convert the direct current to a required DC output power. In this embodiment, the PM unit 24 may also comprise an electronic control module arranged to manage a distribution of available energy across a plurality of consuming devices to maximize lifetime of the devices and while maintaining efficiency. Other components may be used in replacement or in addition to the components of the PM unit 24 without departing from the spirit or scope of the present disclosure.

(44) After powering the battery-free wireless sensor 30, in block 324, the method further comprises (via the sensor 30) sensing an actual condition in the cabin 10. The actual condition is one of actual

temperature and actual humidity in the cabin **10**. As in the examples above, the sensor **30** may be a receiver/transmitter (or transceiver) arranged to receive and transmit signals of a consistent/backscatter protocol (here, RFID) or differing protocols (e.g., BLE, WiFi, LTE, or IoT). Moreover, the sensor **30** is arranged to receive the direct current from the PM unit **24** for power.

(45) Moreover, the sensor **30** is disposed in an area of the cabin **10** (e.g., a head rest) and is arranged to sense, preferably continually sense, the actual condition of an area adjacent or proximate to the head rest. Preferably, the actual condition is temperature or humidity in the cabin **10**. Upon sensing the actual condition, the sensor **30** is arranged to transmit a cabin signal of the actual condition to the controller **32**.

(46) It is to be understood that the sensor **30** may have a varied response time based on a location at which the sensor **30** is disposed and obstructions to the sensor **30**. Relative to the sensor **30**, the varied response time may be defined as a time between being powered and transmitting the cabin signal. For example, the sensor **30** may have a response time of between 5 milliseconds (ms) and 600 ms.

(47) Furthermore in block **326**, the method comprises (via the controller **32**) activating the HVAC unit **212** to adjust one of temperature and humidity in the cabin **10** in response to a difference between the actual condition and a set condition. The set condition is one of a preset temperature and a preset humidity in the cabin **10**. In operation, the controller **32** (via a transceiver or a current driver) may send a drive signal to the HVAC unit **212** which may activate flap controls and activators **218** to thereby provide heating or cooling to the cabin **10** accordingly. In this example, the set condition is one of a preset temperature and a preset humidity in the cabin **10**. That is, the set condition may be preset by an occupant via the HMI unit **220** (FIG. **4A**). Further, the controller **32** may be arranged to store the set condition (e.g., **70F**) and compare the actual condition (e.g., **65F**) with the set condition.

(48) It is to be understood that the controller **32** may implement algorithms and modules to assist in comparisons and calculations relative to climate control of the cabin **10**. It is also to be understood that the controller **32** may be an electronic control unit (ECU), a body control module (BCM), or any other suitable control device without departing from the spirit or scope of the present disclosure.

(49) As discussed above, a plurality of climate control units **14** is preferably disposed throughout the cabin **10** of the vehicle **12** and thereby the climate control units **14** are arranged to sense a plurality of actual conditions across a plurality of locations in the cabin **10**. Thus, the controller **32** may receive the plurality cabin signals of actual conditions from the sensors **30** across the plurality of locations in the cabin **10**. In this example, the step in block **324** of sensing the actual condition in the cabin **10** comprises sensing a plurality of actual conditions across a plurality of locations in the cabin **10**.

(50) Moreover, the step in block **326** of activating the HVAC unit **212** to adjust one of temperature and humidity in the cabin **10** comprises creating the heat map **112** (FIG. **3**) of the cabin **10** from at least a portion of the plurality of actual conditions by way of the interpolation technique (discussed above) with respect to the actual conditions, area of the cabin **10**, and time. Furthermore, the step in block **326** of activating the HVAC unit **212** to adjust one of temperature and humidity in the cabin **10** further comprises adjusting one of temperature and humidity in the cabin **10** with the interpolation technique in response to a difference between the plurality of the actual conditions and a corresponding plurality of the set conditions with the area of the cabin **10**.

(51) The description of the present disclosure is merely exemplary in nature and variations that do not depart from the gist of the present disclosure are intended to be within the scope of the present disclosure. Such variations are not to be regarded as a departure from the spirit and scope of the present disclosure.

Claims

1. A battery-free wireless climate control unit for harvesting wireless energy and for controlling climate in a cabin of a vehicle, the climate control unit comprising: an antenna having a transceiver arranged to receive an electromagnetic (EM) signal of EM radiation having EM energy to define an EM current; a wireless energy harvesting (WEH) unit in communication with the antenna, the WEH unit arranged to filter the EM energy to regulate the EM current and arranged to convert the EM current to direct current; a power management (PM) unit in communication with the WEH unit, the PM unit arranged to store the direct current and arranged to distribute the direct current; a sensor in communication with the PM unit, the sensor arranged to receive the direct current from the PM unit for power, the sensor arranged to sense an actual condition being one of temperature and humidity in the cabin, the sensor arranged to transmit a cabin signal of the actual condition; wherein the sensor is arranged to sense a plurality of actual conditions across a plurality of locations in the cabin; wherein the sensor has a response time of at least 1 millisecond (ms) due to the varied response time of the sensor based on obstructions to the sensor and a location at which the sensor is disposed; a controller in communication with the sensor and the PM unit, the controller arranged to receive the direct current from the PM unit for power, the controller arranged to receive the cabin signal of the actual condition from the sensor, the controller arranged to adjust one of temperature and humidity in the cabin in response to a difference between the actual condition and a set condition, the set condition being one of a preset temperature and a preset humidity in the cabin; and wherein the controller is arranged to create a heat map of the cabin from at least a portion of the plurality of actual conditions by way of an interpolation technique with respect to time and area of the cabin, the controller is arranged to adjust one of temperature and humidity in the cabin with the interpolation technique in response to a difference between the plurality of the actual conditions and a corresponding plurality of the set conditions with the area of the cabin, and the heat map is created from sparse measurements of the cabin to assist with controlling climate in the cabin due to the varied response time of the sensor.
2. A system for harvesting wireless energy for climate control in a cabin of a vehicle, the system comprising: a heating, ventilation, and cooling (HVAC) unit disposed in the vehicle for heating, venting, and cooling the cabin of the vehicle; and a climate control unit in communication with the HVAC unit, the climate control unit comprising: an antenna having a transceiver arranged to receive an electromagnetic (EM) signal of EM radiation having EM energy to define an EM current; a wireless energy harvesting (WEH) unit in communication with the antenna, the WEH unit arranged to filter the EM energy to regulate the EM current and arranged to convert the EM current to direct current; a power management (PM) unit in communication with the WEH unit, the PM unit arranged to store the direct current and arranged to distribute the direct current; a sensor in communication with the PM unit, the sensor arranged to receive the direct current from the PM unit for power, the sensor arranged to sense an actual condition being one of temperature and humidity in the cabin, the sensor arranged to transmit a cabin signal of the actual condition; wherein the sensor is arranged to sense a plurality of actual conditions across a plurality of locations in the cabin; wherein the sensor has a response time of at least 1 millisecond (ms) due to the varied response time of the sensor based on obstructions to the sensor and a location at which the sensor is disposed; a controller in communication with the sensor and the PM unit, the controller arranged to receive the direct current from the PM unit for power, the controller arranged to receive the cabin signal of the actual condition from the sensor, the controller arranged to activate the HVAC unit to adjust one of temperature and humidity in the cabin in response to a difference between the actual condition and a set condition, the set condition being one of a preset temperature and a preset humidity in the cabin; and wherein the controller is arranged to create a heat map of the cabin from at least a portion of the plurality of actual conditions by way of an interpolation technique with

respect to time and area of the cabin, the controller is arranged to adjust one of temperature and humidity in the cabin with the interpolation technique in response to a difference between the plurality of the actual conditions and a corresponding plurality of the set conditions with the area of the cabin, and the heat map is created from sparse measurements of the cabin to assist with controlling climate in the cabin due to the varied response time of the sensor.

3. The system of claim 2 wherein the sensor has a response time between 5 milliseconds and 600 milliseconds.
