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(54) **SYSTEMS AND METHODS FOR ANALYZING HEATING, VENTILATION, AND AIR CONDITIONING SYSTEMS INCLUDING REMOTE MONITORING OF TECHNICIANS**

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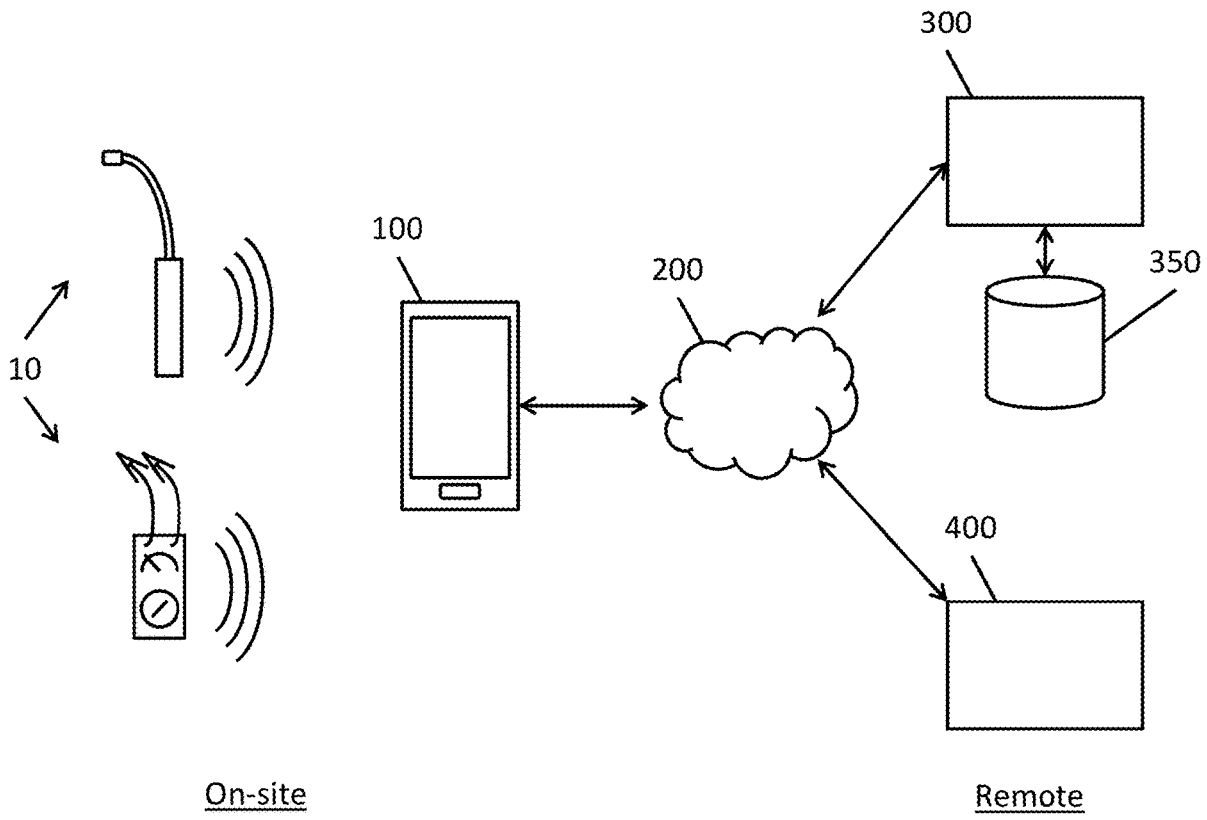
(57) **ABSTRACT**

A system for analyzing a heating, ventilation, and air conditioning (HVAC) system includes: a processor; a display device controlled by the processor; a wireless communication module configured to receive a plurality of measurements from a plurality of different HVAC test instruments arranged to take measurements from the HVAC system, each of the HVAC test instruments providing one or more of the measurements; and a memory having instructions stored thereon where, when the instructions are executed by the processor, cause the processor to: receive the measurements from the different HVAC test instruments via the wireless communication module; convert the measurements to a common format; store the measurements in the common format in the memory; and display the measurements on the display device.



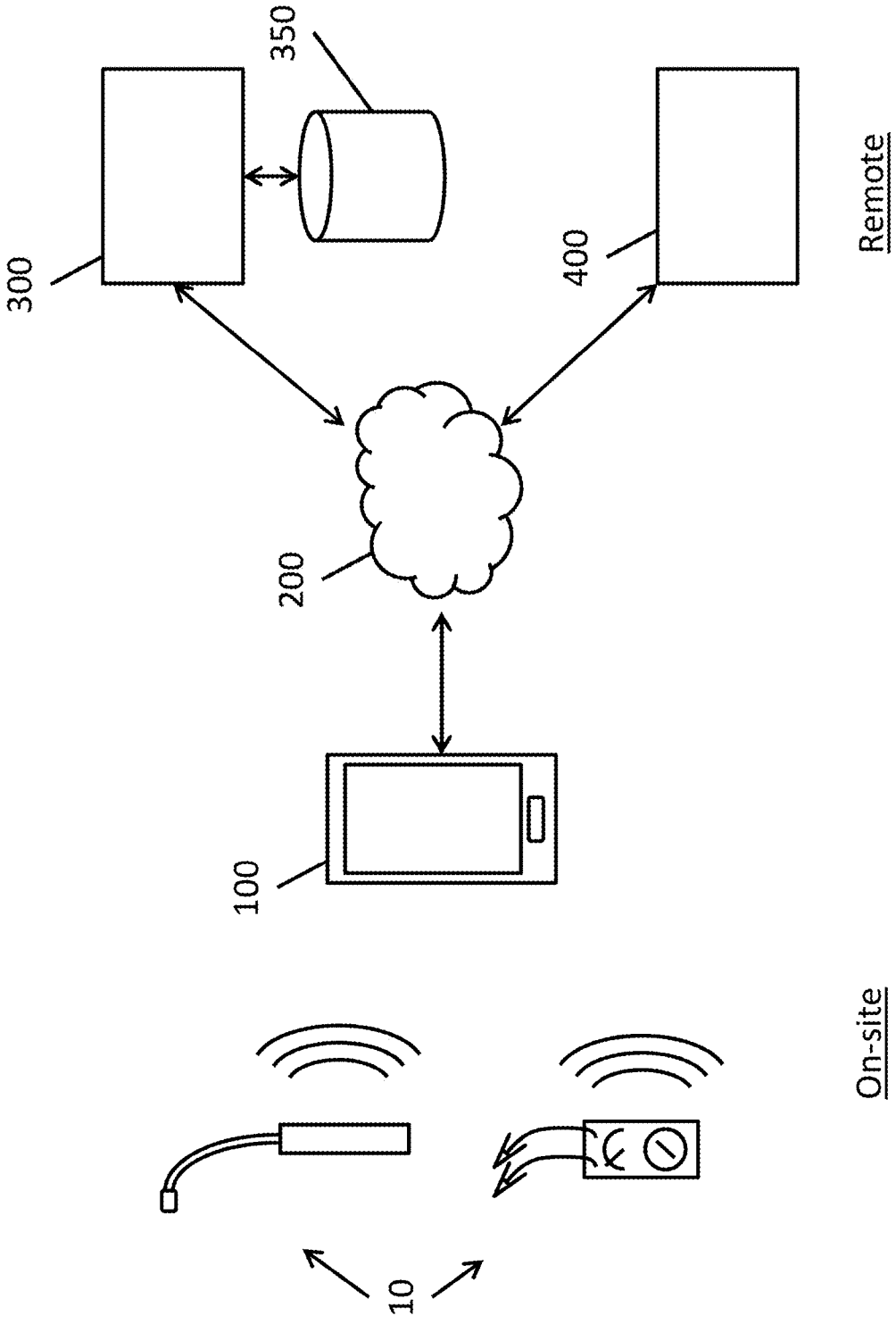


FIG. 1

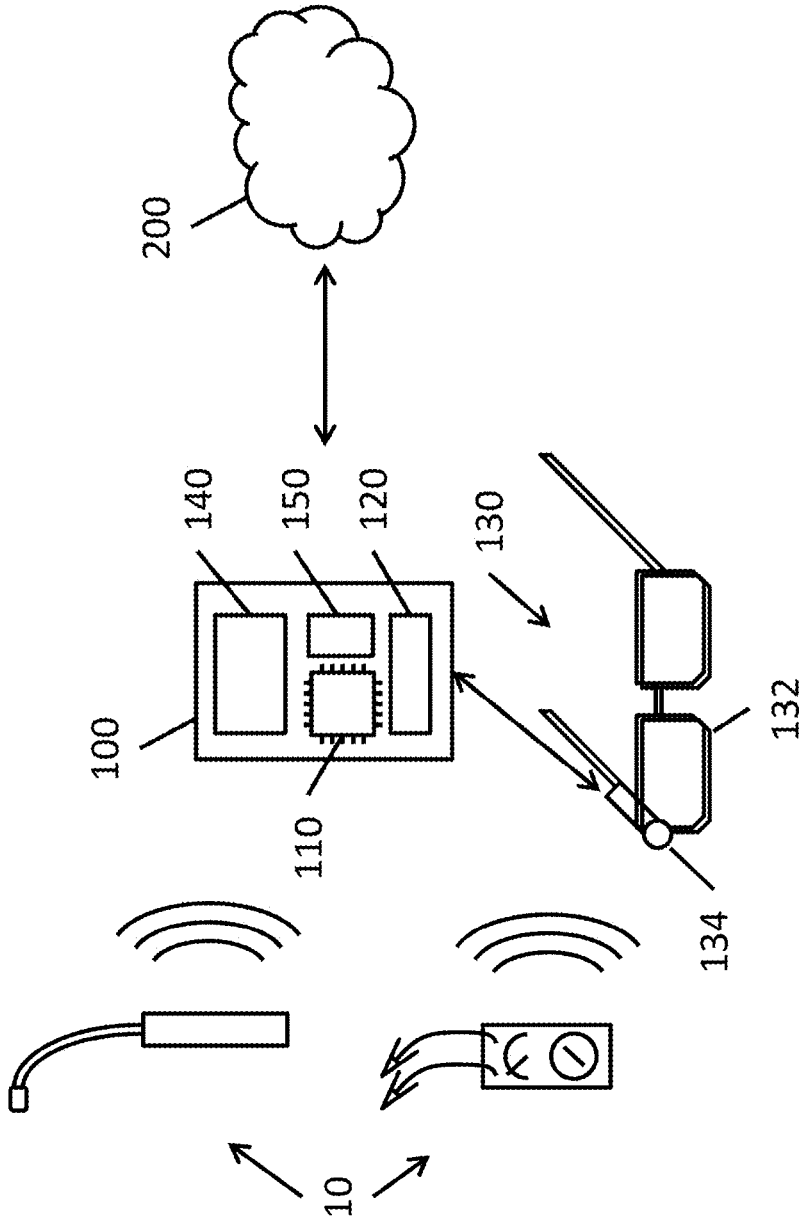


FIG. 2

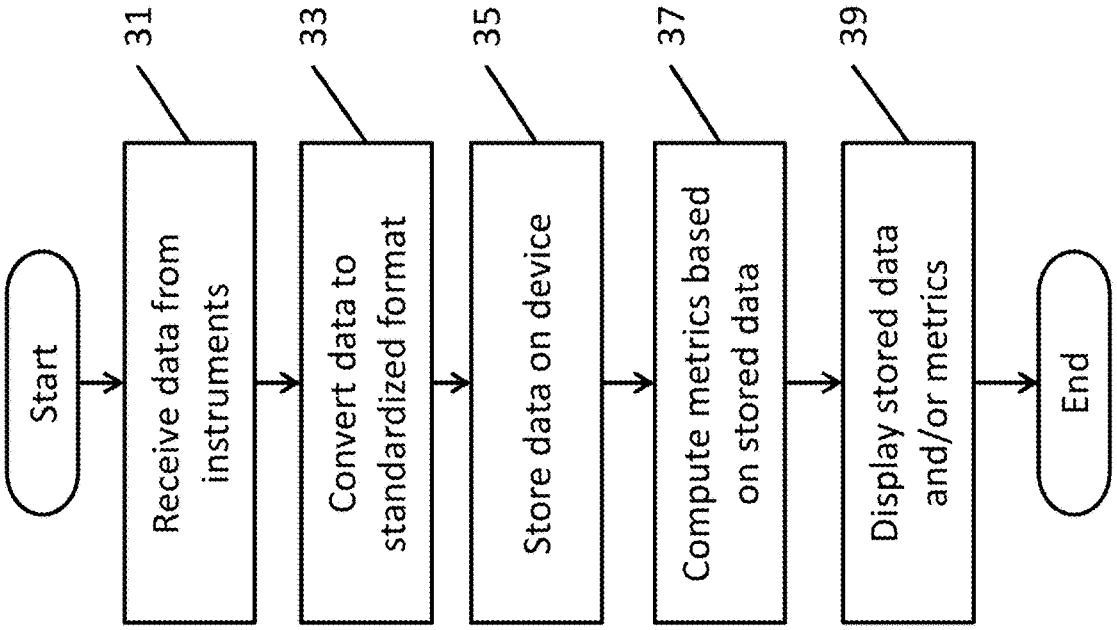

Start
31
Receive data from instruments
33
Convert data to standardized format
35
Store data on device
37
Compute metrics based on stored data
39
Display stored data and/or metrics
End
30

FIG. 3A

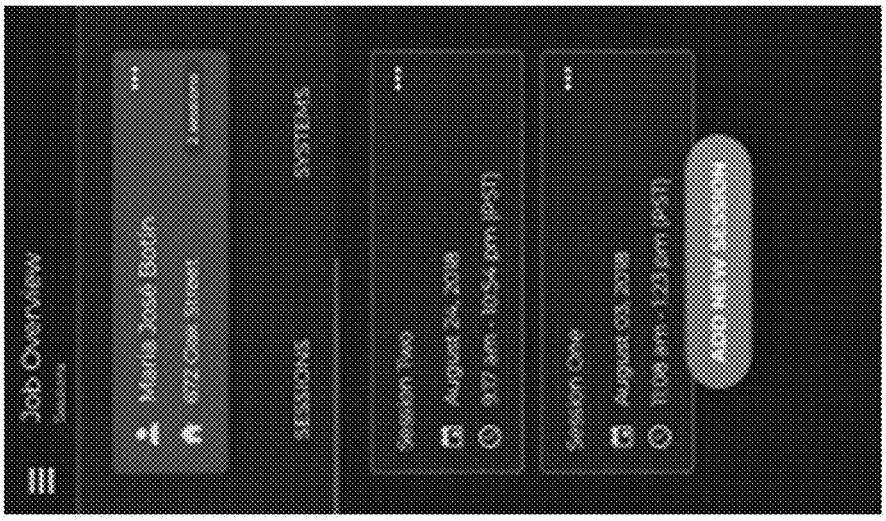


FIG. 3D

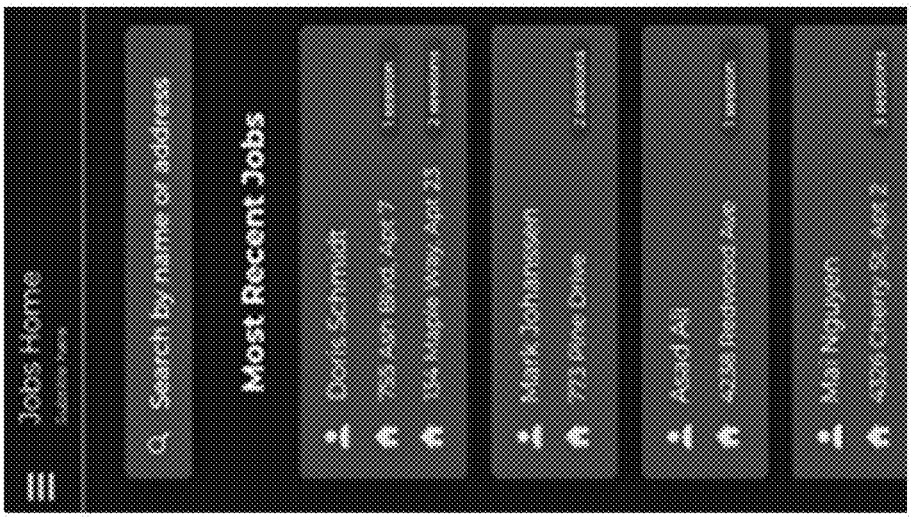


FIG. 3C

FIG. 3B

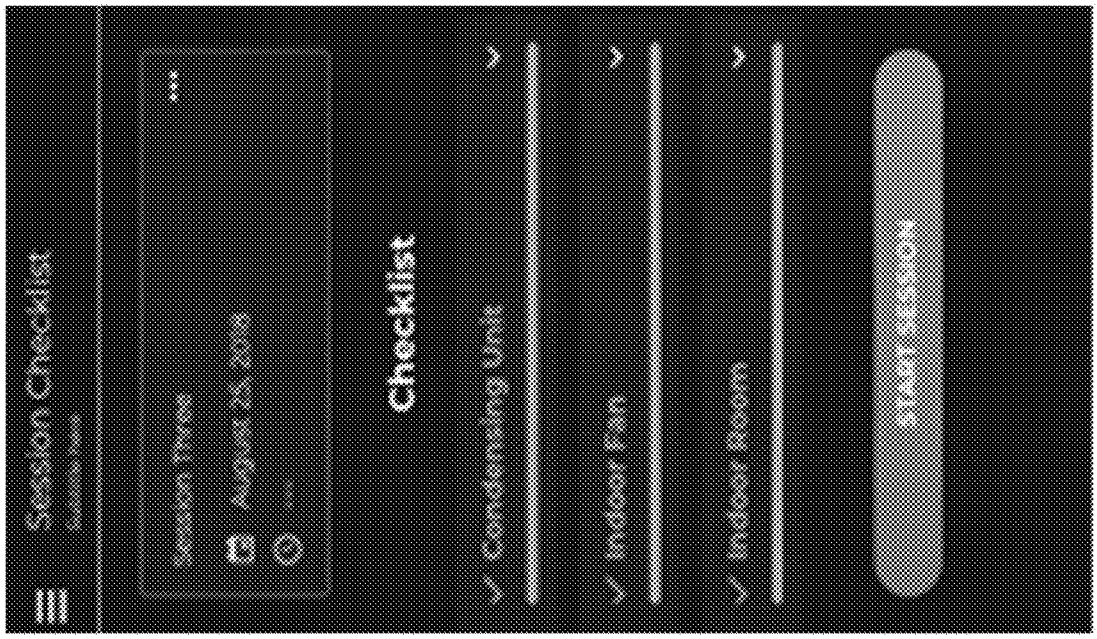

Session Checklist
Session Three
August 25, 2018
Checklist
Condensing Unit
Indoor Fan
Indoor Room
START SESSION

FIG. 3F

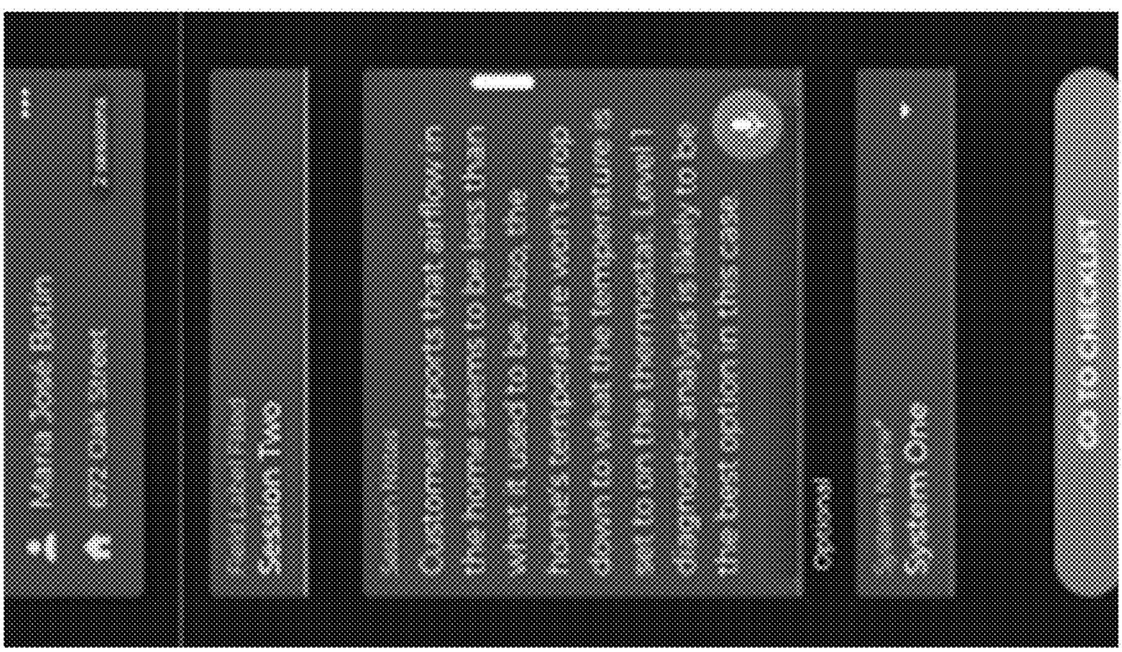

Session Two
Customer reports that airflow in the home seems to be less than what it used to be. Also, the home's temperature won't drop down to what the temperature is set to on the thermostat. Level 1 diagnostic analysis is likely to be the best option in the case
Optional
System One
GO TO CHECKLIST

FIG. 3E

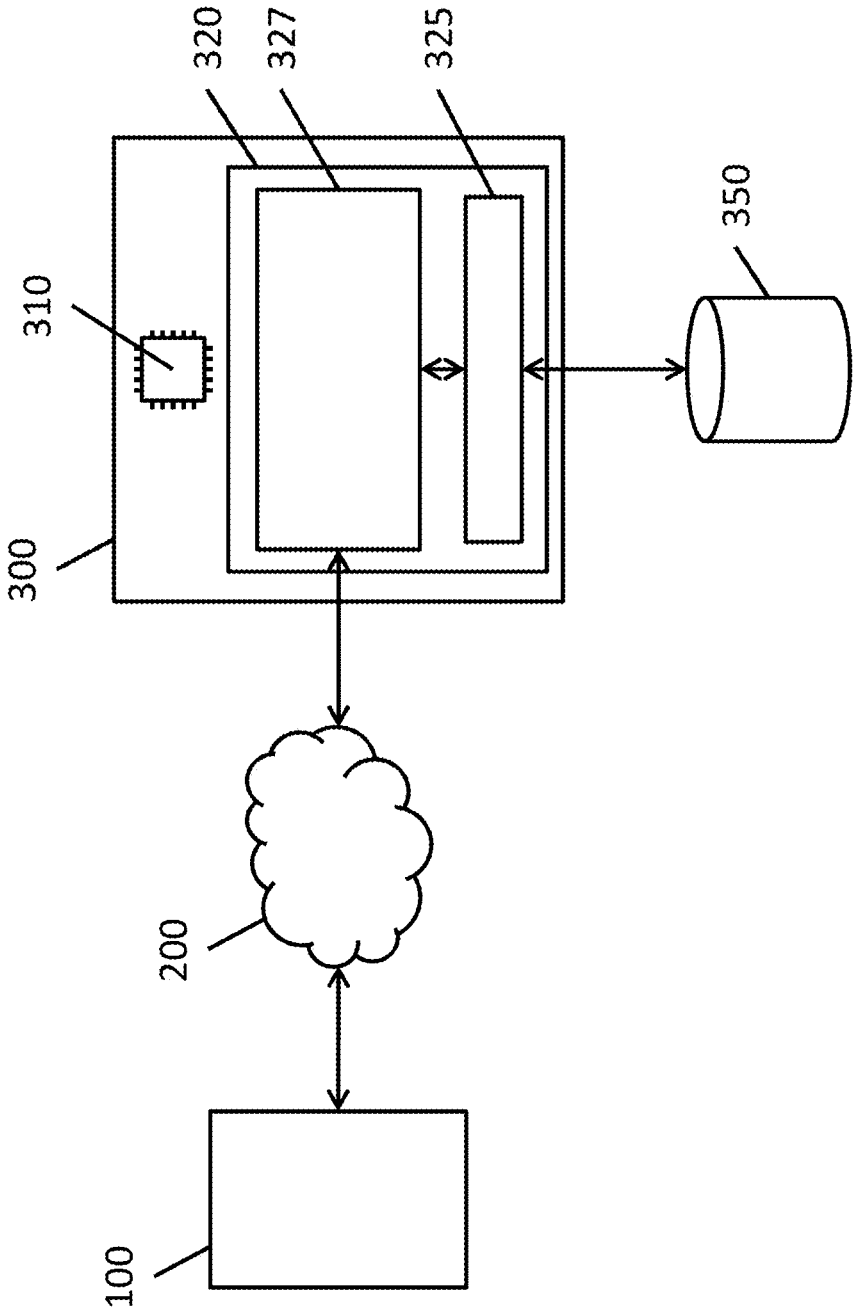


FIG. 4

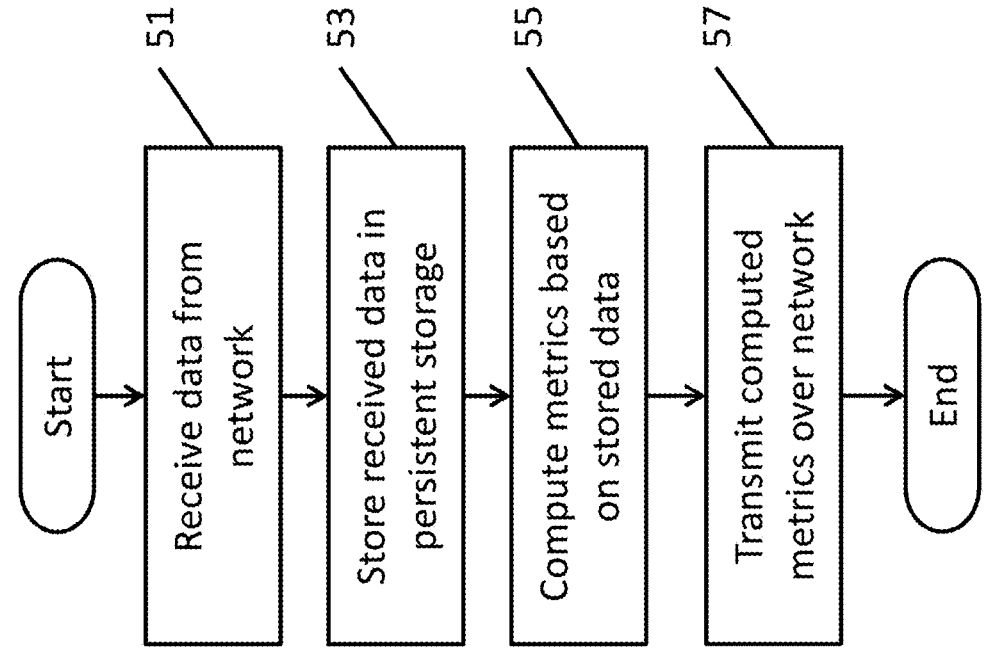

50
Start
Receive data from network
51
Store received data in persistent storage
53
Compute metrics based on stored data
55
Transmit computed metrics over network
57
End

FIG. 5

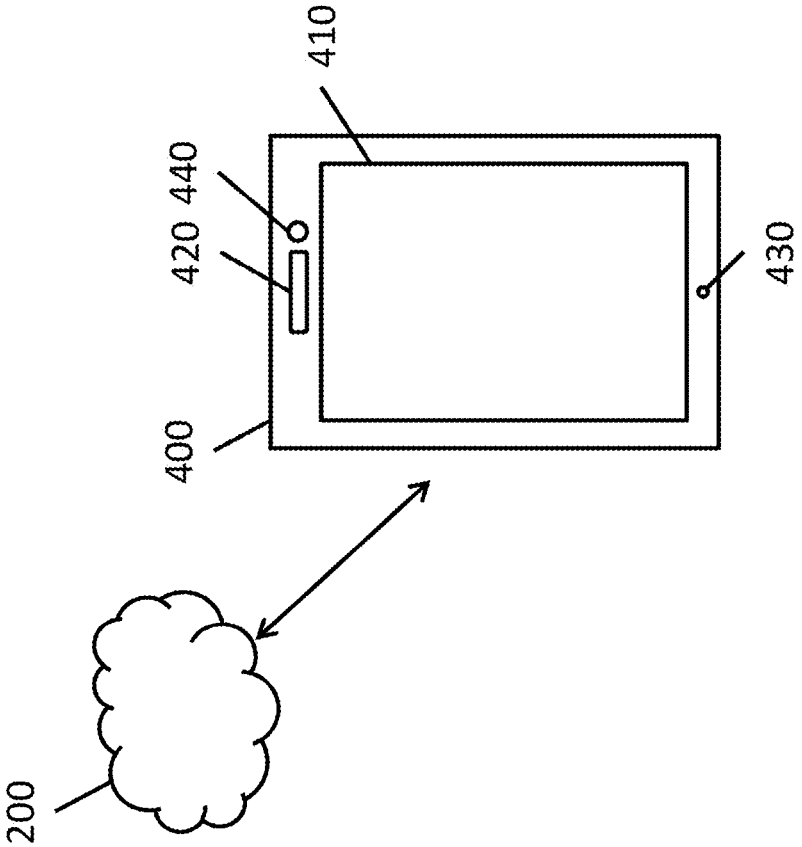
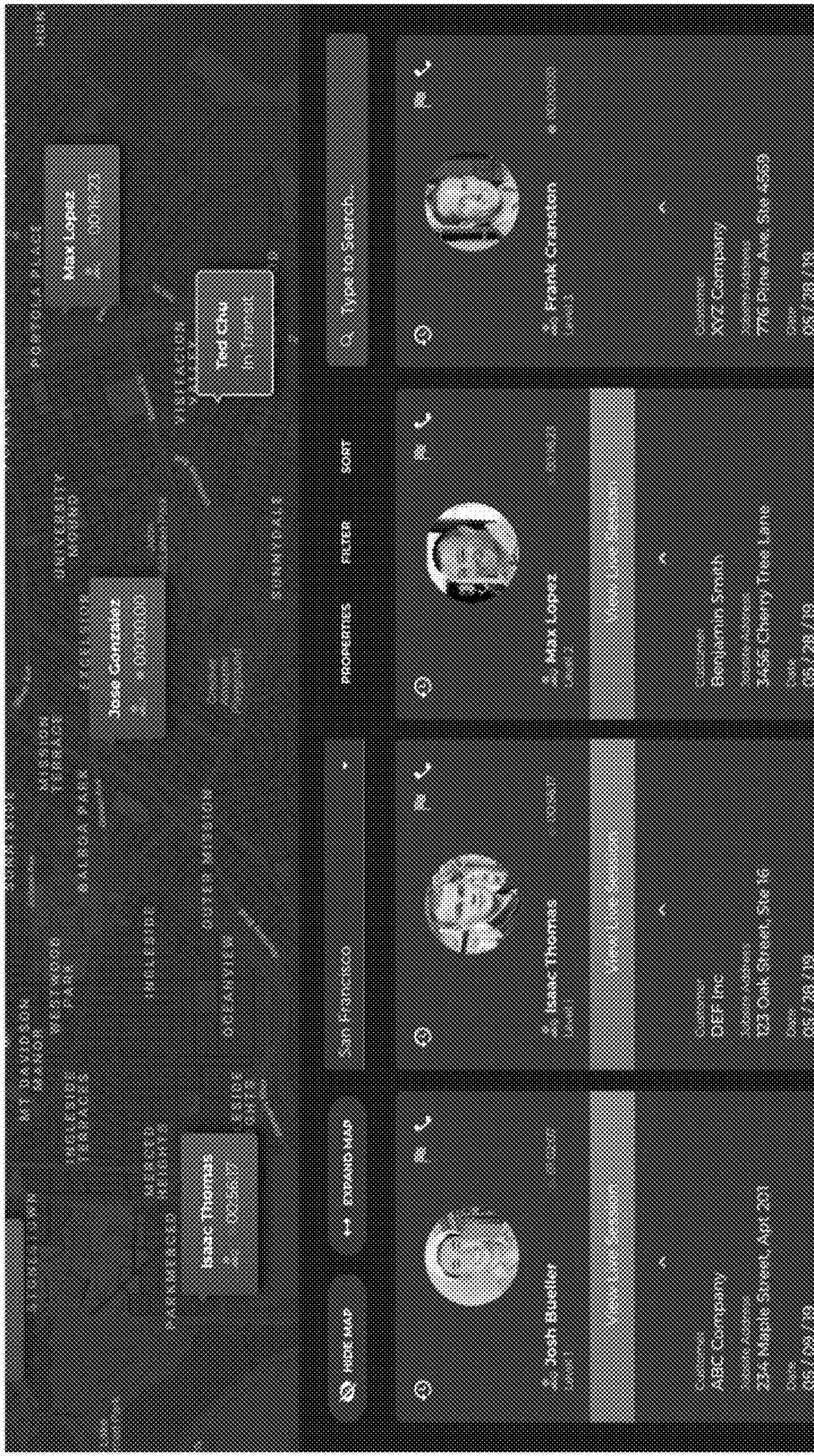


FIG. 6A

600

602



604

FIG. 6B

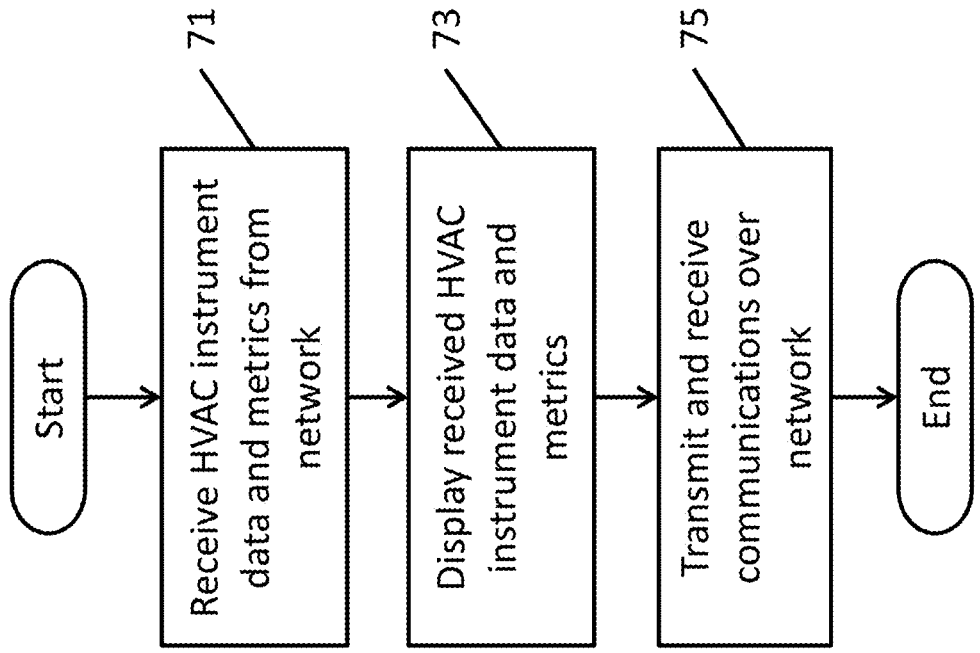

70
Start
Receive HVAC instrument data and metrics from network
71
Display received HVAC instrument data and metrics
73
Transmit and receive communications over network
75
End

FIG. 7A

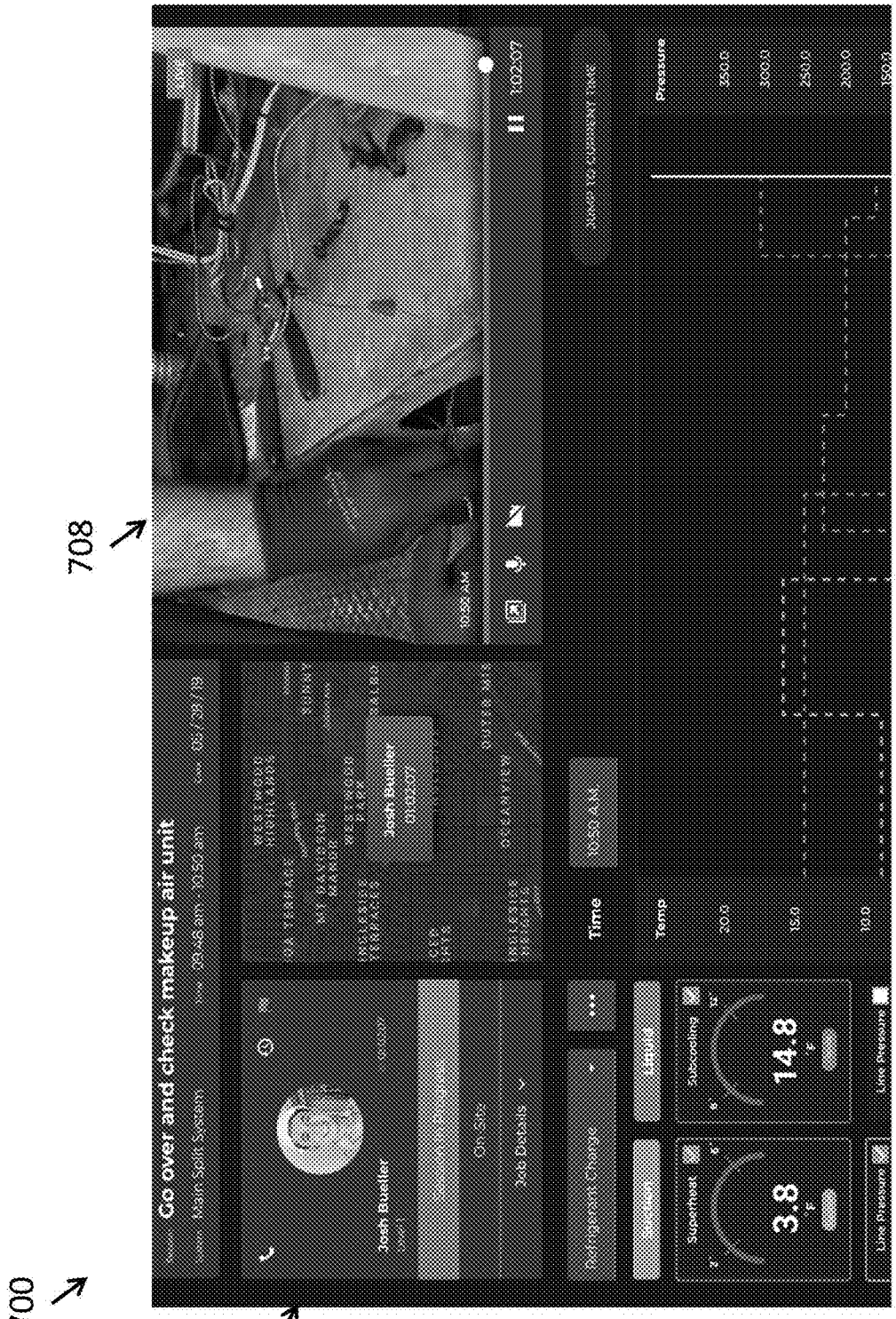

700
702
704
706
708
Go over and check makeup air unit
Josh Bueller
Temp
Pressure
14.8
3.8

FIG. 7B

SYSTEMS AND METHODS FOR ANALYZING HEATING, VENTILATION, AND AIR CONDITIONING SYSTEMS INCLUDING REMOTE MONITORING OF TECHNICIANS

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] This application is a continuation of U.S. patent application Ser. No. 16/541,031 filed Aug. 14, 2019, which claims priority to and the benefit of U.S. Provisional Patent Application No. 62/718,940, filed in the United States Patent and Trademark Office on Aug. 14, 2018, the entire disclosure of each of which is incorporated by reference herein.

FIELD

[0002] Aspects of embodiments of the present invention relate to the field of systems and methods for monitoring heating, ventilation, and air conditioning systems and the automatic analysis of data associated with heating and air conditioning systems.

BACKGROUND

[0003] In the field of heating, ventilation, and air conditioning (HVAC) systems, various test instruments are used to measure parameters of the system. These instruments may include, for example, velometers (air speed meters), balometers (air flow meters), manometers (static air pressure sensors), temperature sensors (both dry bulb and wet bulb temperature sensors), megohmmeters, voltmeters, ammeters, ohmmeters, multimeters, and the like. An on-site HVAC technician typically uses the various test instruments to measure the condition and performance of an HVAC system.

SUMMARY

[0004] Aspects of embodiments of the present invention relate to systems and methods for automatically collecting and compiling data from disparate test instruments deployed at a site of a heating, ventilation, and air conditioning (HVAC) system to measure the performance of the HVAC system and displaying the collected and compiled data to an on-site HVAC technician.

[0005] Aspects of embodiments of the present invention also relate to transmitting the collected test instrument data for display to a remote HVAC technician over a telecommunications network or computer network (e.g., a cellular network and/or the Internet). Some aspects of embodiments of the present invention further relate to transmitting audio and/or video data from the site containing the HVAC system to the remote HVAC technician. Aspects of some embodiments relate to providing training to an on-site HVAC technician from a remote HVAC technician, where the information collected by the on-site instruments and/or the video data are automatically provided to the remote HVAC technician.

[0006] Additional aspects of embodiments of the present invention relate to the automatic analysis of the collected data to compute performance metrics and to evaluate the performance of the HVAC system against standards such as building codes or government regulatory standards (for example, the California Building Standards Code found in Title 24 of the California Code of Regulations and agency rules such as California Energy Commission rules on building HVAC efficiency standards). Further aspects of embodiments of the present invention relate to automatically generating reports from the data collected from the test instruments.

[0007] According to one embodiment of the present invention, a system for analyzing a heating, ventilation, and air conditioning (HVAC) system includes: a processor; a display device controlled by the processor; a wireless communication module configured to receive a plurality of measurements from a plurality of different HVAC test instruments arranged to take measurements from the HVAC system, each of the HVAC test instruments providing one or more of the measurements; and a memory having instructions stored thereon where, when the instructions are executed by the processor, cause the processor to: receive the measurements from the different HVAC test instruments via the wireless communication module; convert the measurements to a common format; store the measurements in the common format in the memory; and display the measurements on the display device.

[0008] The plurality of different HVAC test instruments may include at least two HVAC test instruments selected from: a temperature sensor; a velometer; a balometer; a manometer; a pressure sensor; or a multimeter.

[0009] The memory may further store instructions that, when executed by the processor, cause the processor to: compute one or more metrics based on the measurements; and display the computed one or more metrics.

[0010] The memory may further stores instructions that, when executed by the processor, cause the processor to: retrieve a plurality of previously stored measurements from the memory; and display a plurality of line graphs of the previously stored measurements over time.

[0011] The memory may further store instructions that, when executed by the processor, cause the processor to: compute one or more metrics over time based on the previously stored measurements; and display one or more line graphs of the one or metrics computed based on the previously stored measurements.

[0012] The system may further include a network adapter, wherein the memory may further store instructions that, when executed by the processor, cause the processor to: transmit the measurements to a computer server via the network adapter; receive one or more metrics from the computer server via the network adapter; and display the one or more metrics on the display device.

[0013] The system may further include a network adapter, wherein the memory may further store instructions that, when executed by the processor, cause the processor to: transmit the measurements to a computer server via the network adapter; establish a communication channel with a remote computer, the remote computer including a remote display device displaying the measurements; and transmit audio and video via the communication channel.

[0014] The memory may further store instructions that, when executed by the processor, cause the processor to: receive audio via the communication channel.

[0015] The memory may further store instructions that, when executed by the processor, cause the processor to: receive, via the communication channel, an annotation corresponding to a measurement displayed on the display device; and display the annotation on the display device.

[0016] The memory may further store instructions that, when executed by the processor, cause the processor to:

compare the measurements to one or more standards stored in the memory to compute a comparison; and compute compliance with the one or more standards based on the comparison.

[0017] According to one embodiment of the present invention, a method for analyzing a heating, ventilation, and air conditioning (HVAC) system at a site includes: receiving, by an on-site computing system, a plurality of measurements from a plurality of different HVAC test instruments arranged to take measurements from the HVAC system, each of the HVAC test instruments providing one or more of the measurements via a wireless communication module; converting, by the on-site computing system, the measurements to a common format; storing, by the on-site computing system, the measurements in the common format in a memory of the on-site computing system; and display, on a display device of the on-site computing system, the measurements on the display device.

[0018] The plurality of different HVAC test instruments may include at least two HVAC test instruments selected from: a temperature sensor; a velometer; a balometer; a manometer; a pressure sensor; or a multimeter.

[0019] The method may further include: computing one or more metrics based on the measurements; and displaying the computed one or more metrics.

[0020] The method may further include: retrieving a plurality of previously stored measurements from the memory; and displaying a plurality of line graphs of the previously stored measurements over time.

[0021] The method may further include: computing one or more metrics over time based on the previously stored measurements; and displaying one or more line graphs of the one or metrics computed based on the previously stored measurements.

[0022] The method may further include: transmitting the measurements to a computer server via a network adapter; receiving one or more metrics from the computer server via the network adapter; and displaying the one or more metrics on the display device.

[0023] The method may further include: transmitting the measurements to a computer server via a network adapter; establishing a communication channel with a remote computer, the remote computer including a remote display device displaying the measurements; transmitting audio and video captured by the on-site computing device to the remote computer via the communication channel; and receiving audio via the communication channel.

[0024] The method may further include: receiving, via the communication channel, an annotation corresponding to a measurement displayed on the display device; and displaying the annotation on the display device.

[0025] The method may further include: comparing the measurements to one or more standards stored in the memory to compute a comparison; and computing compliance with the one or more standards based on the comparison.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] The accompanying drawings, together with the specification, illustrate exemplary embodiments of the present invention, and, together with the description, serve to explain the principles of the present invention.

[0027] FIG. **1** is a block diagram of a system according to one embodiment of the present invention for providing monitoring and analysis of a heating, ventilation, and air conditioning (HVAC) system.

[0028] FIG. **2** is a block diagram of a field or on-site system according to one embodiment of the present invention.

[0029] FIG. **3**A is a flowchart of a method for collecting, analyzing, and displaying sensor data according to one embodiment of the present invention.

[0030] FIG. **3**B is a screenshot of a user interface of an application according to one embodiment of the present invention displaying readings from a plurality of on-site instruments.

[0031] FIG. **3**C is a screenshot of a user interface of an application according to one embodiment of the present invention displaying a list of recent jobs, providing access to recorded data from measurements taken at the various jobs.

[0032] FIG. **3**D is a screenshot of a user interface of an application according to one embodiment of the present invention displaying a list of sessions at a selected job site.

[0033] FIG. **3**E is a screenshot of a user interface of an application according to one embodiment of the present invention displaying notes taken by a technician regarding their experience at a job site.

[0034] FIG. **3**F is a screenshot of a user interface of an application according to one embodiment of the present invention displaying a checklist of items to review at a particular job site.

[0035] FIG. **4** is a block diagram of a computer server system according to one embodiment of the present invention.

[0036] FIG. **5** is a flowchart of a method for storing and analyzing data according to one embodiment of the present invention.

[0037] FIG. **6**A is a block diagram of a remote computing system according to one embodiment of the present invention.

[0038] FIG. **6**B is a screenshot of a user interface of a remote monitoring application for dispatching technicians according to one embodiment of the present invention running on a remote computing system.

[0039] FIG. **7**A is a flowchart of a method for displaying collected data on a remote computing system and providing feedback according to one embodiment of the present invention.

[0040] FIG. **7**B is a screenshot of a user interface of a remote monitoring application for remotely monitoring a technician according to one embodiment of the present invention running on a remote computing system.

DETAILED DESCRIPTION

[0041] In the following detailed description, only certain exemplary embodiments of the present invention are shown and described, by way of illustration. As those skilled in the art would recognize, the invention may be embodied in many different forms and should not be construed as being limited to the embodiments set forth herein.

[0042] Aspects of embodiments of the present invention are related to addressing current problems in the installation and maintenance of heating, ventilation, and air conditioning (HVAC) system and other skilled trades that involve on-site operations. Based on retrospective analysis, when needed in the field, technicians receive timely and correct assistance less than 50% of the time. Most technicians do not have access to high quality hands-on training or ongoing men-

torship by experienced technicians. As a result, it generally takes three to five years for technicians to become self-reliant in the field and to make living wages. Contractors report that finding trained and qualified technicians is a major problem in meeting customer demand and growing their business. However, contractors do not have a way of remotely monitoring the quality of services provided by technicians or assessing the skills of technicians in the field. Furthermore, there is a need for tools to systematically record and archive field service history. HVAC contractors have generally recruited and trained their field employees the same way for over 40 years. However, the aging workforce in the field and low rates in attracting, developing, and sustaining technicians threaten the trade. Furthermore, the HVAC industry has very low energy code compliance. In addition, the only information that most customers receive regarding the service they receive is an invoice. Customers generally do not have access to details of their overall HVAC system diagnostics and indicators, do not awareness of their system's energy footprint, and do not receive actionable data about the health of their HVAC equipment at the time of the service or over time.

[0043] Accordingly, various aspects of embodiments of the present invention relate to automating aspects of the processes of measuring, analyzing, and reporting on the status of HVAC systems in the field, as measured by potentially disparate HVAC instruments deployed in a job site. The automated collection, aggregation, and canonicalization of the data allows these data to be presented to the technician and remote trainers or coaches, thereby improving the ability of remote technicians to provide useful advice, and thereby improving the process of training junior technicians, as an experienced remote technician can concurrently provide support to multiple junior technicians in the field. These systems also allow for the automatic generation of customer-facing and contractor-facing reports and the automatic evaluation of the measured data against standards such as energy efficiency standards to determine energy code compliance.

[0044] FIG. **1** is a block diagram of a system according to one embodiment of the present invention for providing monitoring and analysis of a heating, ventilation, and air conditioning (HVAC) system. Aspects of embodiments of the present invention relate to systems and methods for collecting, integrating, and computing metrics from sensor data collected from heating, ventilation, and air conditioning (HVAC) instruments ("on-site" sensors) **10** that are distributed in various sections of an HVAC system (an "on-site" HVAC system). Some aspects of embodiments of the present invention relate to aggregating and presenting the data collected from different instruments or disparate instruments on a display device of an on-site computing system (e.g., a smartphone or tablet computer) **100** that is used by an on-site HVAC technician, thereby allowing the on-site HVAC technician to develop a better or more comprehensive or integrated understanding of the operation of the full HVAC system and its interaction with, for example, the building or structure (e.g., a house) at which it is installed. In contrast, in comparative systems, individual instruments may have separate read-out displays, whether on the device itself (e.g., an LCD display built into the device) or accessible through separate, instrument specific software applications (or "app").

[0045] In some embodiments of the present invention, the HVAC instruments **10** transmit the sensor data to the computing system **100** over a wireless data connection, such as Bluetooth Low Energy (BLE) (IEEE 802.15.1) or Zigbee (IEEE 802.15.4). Some aspects of embodiments of the present invention relate to computing metrics, such as HVAC system power efficiency, based on the collected data. Other aspects of embodiments of the present invention relate to storing the data collected over time, thereby enabling embodiments of the present invention to display graphs (e.g., line graphs) of the data and/or metrics over time (e.g., as the system is perturbed or otherwise subjected to different operating conditions).

[0046] Some aspects of embodiments of the present invention relate to transmitting the collected data over a computer network **200**, such as the Internet, and storing the collected data on a cloud-based computer server **300** and/or a cloud database **350**. The computer server **300** may also perform calculations using the collected data, such as comparing the collected data to previously collected data from other HVAC systems that is stored in the database. The computer server **300** may transmit the collected information back to the computing system **100** used by the on-site HVAC technician to provide additional context for the information collected by the on-site HVAC instruments.

[0047] Some additional aspects of embodiments of the present invention relate to transmitting the data collected from the on-site HVAC instruments **10** to another computer system (a "remote" computer system) **400**, where a remote HVAC technician serving as a trainer, mentor, or coach to the on-site HVAC technician can monitor the measurements taken by the on-site HVAC technician using the on-site HVAC instruments. Further aspects of embodiments of the present invention provide for communication between the on-site HVAC technician and the remote HVAC technician, such as audio (e.g., a phone call between the HVAC technician and the remote technician), live video (e.g., of the view seen by the on-site HVAC technician, the faces of the on-site HVAC technician and the remote HVAC technician, and combinations thereof), text chat, and other system-specific communications, such as displaying collaborative annotations on various portions of the graphs of data, screen sharing, and the like.

[0048] FIG. **2** is a block diagram of a field or on-site system according to one embodiment of the present invention. As discussed above, in the field of HVAC systems, various test instruments or test equipment are used to measure parameters of an HVAC system at a site. As non-limiting examples, these instruments **10** may include velometers (air speed meters), balometers (air flow meters), manometers (static air pressure sensors), temperature sensors (e.g., both dry bulb and wet bulb temperature sensors and/or thermometers), megohmmeters (to measure the electrical resistance of insulators), and other electrical instruments (e.g., voltmeters, ammeters, ohmmeters, multimeters, and the like), which are sold under the brand names, for example, Fieldpiece®, Yellow Jacket®, and Fluke®. Many models of test equipment include wireless communication hardware for communicating using protocols such as Bluetooth® (e.g., devices compliant with the IEEE 802.15.1 standard). Bluetooth Low Energy (BLE) is one variant of Bluetooth®. These wireless communication hardware allows the test instruments to communicate with compatible

computing systems **100** such as Bluetooth-enabled smartphones, tablet computers, and laptop computers.

[0049] A computing system **100** that is deployed on-site at the HVAC system or in the field may include, without limitation thereto, a computer processor **110** and memory **120** storing instructions to be executed by the processor **110** to perform various operations associated with embodiments of the present invention. The memory **120** may include dynamic memory (DRAM) and persistent memory (e.g., NAND flash memory, static memory or SRAM, and/or a hard disk drive). The memory **120** may also store other information, such as the sensor data (or "measurements") received from the test instruments **10**, application software ("apps"), images, service manuals, and the like.

[0050] Prior to the development of test instruments having wireless communications hardware, taking measurements in different parts of an HVAC system (e.g., in a building or structure such as a house) would require the on-site HVAC technician to be physically present at the place of measurement. For example, an on-site HVAC technician may use a multi-meter (e.g., voltmeter and/or ammeter) to make electrical measurements at components of an HVAC unit such as the compressor motor, condenser fan, or blower motor, which may be located inside or outside of the structure, and may, separately, take air pressure readings at various points in the ductwork inside the structure, as well as temperature readings and air flow (e.g., balometer) measurements at different places within the structure. These test instruments generally require a person to be physically at the test instrument **10** to perform a reading from an integrated meter, gauge, or other integrated display of the test instrument **10**. As a result, only a few different readings are available to the technician at a given time. This can make it difficult for an on-site HVAC technician to develop a comprehensive or integrated view of an installed HVAC system, because the test instruments located in different parts of the site may provide sparse data at different time points (e.g., 30 to 60 minutes apart). For example, a multimeter connected to the power supply of a compressor may be located a long distance away from a balometer in a particular room of a building, making it difficult to interpret the relationship between power usage at the compressor and the air flow in the particular room.

[0051] In circumstances where the test instruments include wireless communications capabilities, an on-site HVAC technician can leave an instrument in one location and receive readings from it (via a compatible computing device) from locations within the range of the device (in the case of a direct wireless connection between the instrument and the computing device) or from any network-enabled device (in the case where the instrument is connected to a computer network).

[0052] While such wireless communications capabilities enable the display of the measurements of individual test instruments on a compatible computing device, this information is generally constrained (or "siloed") for use within a particular software application (or "app") provided by the manufacturer of the test instrument. For example, if the wireless multi-meter is manufactured by one company and an air flow meter (or balometer) is manufactured by a different company, then it may be difficult or impossible to view both measurements at the same time and may be difficult or impossible to automatically compute metrics that depend on both values (e.g., that depend on values that are siloed in their respective apps). As such, HVAC technicians in these circumstances may need to manually calculate such values by inputting the measurements into a calculator program or look up metrics using a chart. These manual calculations may also make it difficult to observe the dynamics of the calculated values over time as various conditions change in the HVAC system.

[0053] As such, aspects of embodiments of the present invention relate to systems and methods for collection and analysis of test instrument data. For example, the test instruments can be configured to capture data and transmit the data to the computing device **100** every second, every 30 seconds, every minute, and the like. Accordingly, embodiments of the present invention allow for substantially continuous monitoring of parameters across the HVAC system, at least because the HVAC instruments can be left in each location during the testing of the HVAC system.

[0054] In some embodiments of the present invention, the computing system **100** may is connected to a pair of smart glasses or goggles (or other head-mounted display device such as Google Glass® or Microsoft® HoloLens®) **130**. The glasses **130** may include one or more display devices **132** configured to display information to a wearer of the glasses **130** (e.g., an on-site HVAC technician). The display devices **132** may be configured to operate in an augmented reality (AR) fashion, where information in overlaid onto a view of a scene. The glasses **130** may also include a camera **134** configured to capture images a portion of a scene in front of the wearer of the glasses **130**. The computing system **100** may also include a display device **140** configured to show information such as the measurements received from the instruments **10**. In some embodiments, the display device **140** is also an input device (e.g., in the case of a touch sensitive display). In some embodiments, the computing system **100** includes other user input functionality, such as buttons, keyboards, control wheels, and the like. In some embodiments, the computing system **100** further includes one or more wireless network adapters **150** that are configured to communicate with a wireless local area network (WLAN or WiFi) and/or a wireless wide area network (WWAN) such as a cellular wireless data network (e.g., a Long Term Evolution (LTE) wireless network).

[0055] FIG. **3**A is a flowchart of a method **30** for collecting, analyzing, and displaying sensor data according to one embodiment of the present invention. As shown in FIG. **3**A, in operation **31**, the computing system **100** receives data from the test instruments **10**. As discussed above, the data may be received over a wireless data connection (such as a Bluetooth® data connection, a Zigbee® data connection, or a WiFi data connection). In operation **33**, the data received from the instruments is converted to a standardized (or canonical) format. This may include, for example, converting data values to particular standardized ranges, changing data to particular standardized units, and the like. For example, the computing system **100** may be configured to store temperature measurements in degrees Fahrenheit, but a temperature sensor may be configured to report temperatures in degrees Celsius or kelvin, or on a different scale (e.g., an eight-bit value, where a 0 value may correspond to a temperature of 32 degrees Fahrenheit, value of 255 may correspond to a temperature of 150 degrees Fahrenheit.

[0056] In some aspects of embodiments of the present invention, one or more of the test instruments **10** transmit data to the computing system **100** in accordance with a

standardized format and/or standardized protocol. The standardized format and/or protocol may be defined by a standard setting organization or other appropriate organization (such as an industry trade group or trade association). The standardized format may also be defined in accordance with an application programming interface (API), such as a Representational State Transfer (REST) based API. A standardized format, protocol, and/or APIs in accordance with some embodiments of the present invention includes features and characteristics that are particular to the domain of embodiments of the present invention, such as specifying data formats (e.g., canonical data formats) for each type of test instrument (e.g., specific data structures or data types for thermometers, velometers, balometers, manometers, voltmeters, and the like) and such as specifying particular use cases (e.g., the use of particular instruments in particular locations, such as a velometer at an intake or a voltmeter on a circulating fan). The use of standardized data formats allows for comparisons of like data (e.g., air flow data or temperature data) as measured by HVAC instruments **10** manufactured by different companies and also allows such data to be displayed and compared on the same user interface without requiring further conversion or adjustment. Accordingly, different manufacturers of test instruments can configure their products to communicate with the computing system **100** of embodiments of the present invention using a standardized format, standardized protocol, and/or application programming interface in accordance with embodiments of the present invention. In some embodiments, data that is received in a proprietary of specialized format may be canonized into the standardized data format.

[0057] In operation **35**, the converted and/or standardized data is stored in the computing system **100**, such as in memory **120**, where it can be retrieved for later display as part of a line graph and/or to compute metrics in operation **37**. In operation **37**, the computing system **100** computes metrics based on the stored data. The metrics may include statistics relating to single streams of sensor data (e.g., moving averages and standard deviations of sensor data over time such as temperature readings from one part of the HVAC system). The metrics may also include values that are computed from different measurements (e.g., a difference between two different temperatures from two different parts of the HVAC system and/or values computed from two or more different types of instruments). The metrics may relate to performance indicators of interest in the context of government regulations (e.g., building codes) and agency rules (e.g., energy efficiency standards). Specific examples of metrics include: subcooling and/or superheat calculations (related to proper refrigerant charge); motor performance coefficients (the current performance metrics of individual motors in the HVAC system such as an indoor fan motor, a condenser fan motor, and a compressor); power factor calculations; field energy efficiency ratio (FEER) (a high level overview of the efficiency of the system being tested); pressure profiles; and changes in moisture readings through a duct (as potentially indicative of leakage). The computed metrics may also be stored in the memory **120** to be displayed on a display device. In some embodiments of the present invention, the computed metrics are automatically compared against system-specific performance requirements (e.g., performance requirements set by government codes or regulations) to compute comparisons, and the computed comparisons (e.g., indicating compliance or non-compliance with performance requirements or standards) may be displayed on the smart glasses **130** and/or the display device **140**.

[0058] In operation **39**, the stored data and/or the metrics computed in operation **37** are displayed on the smart glasses **130** (if available) and/or on the display device **140** of the computing system **100**. As such, aspects of embodiments of the present invention allow for the automatic collection, storage, and display of data collected from HVAC test instruments **10**. In addition, aspects of embodiments of the present invention allow for the automatic computation of metrics based on the collected data and display of the metrics to HVAC technicians. Accordingly, embodiments of the present invention integrate data from disparate sources (e.g., different HVAC test instruments **10**) to provide HVAC technicians with a comprehensive or integrated view of an HVAC system (e.g., a "whole building" or "whole house" view), thereby allowing easier analysis of the performance of such systems. In some embodiments, the comparisons of the computed metrics against the system-specific performance requirements are also displayed to the technician (e.g., "in compliance" versus "not in compliance"), thereby assisting the technician in determining whether further adjustments may be necessary to the system and/or the impact of various changes on the overall performance metrics.

[0059] In some embodiments, the computing system **100** transmits the data received from the HVAC test instruments **10**, over a network **200**, to a data storage and processing system or computer server **300**. The data storage and processing system **300** may be a remote device (e.g., located at a distance from the site of the HVAC system), such as in one or more data centers of one or more cloud computing services.

[0060] FIGS. **3**B, **3**C, **3**D, **3**E, and **3**F are screenshots of user interfaces of an application according to one embodiment of the present invention.

[0061] FIG. **3**B is a screenshot of a user interface of an application according to one embodiment of the present invention displaying readings from a plurality of on-site instruments. Field technicians can connect (or "pair") the deployed instruments with the on-site computing system **100** in order to receive the data in the application. The user interface shown in FIG. **3**B depicts six readings including: dry bulb temperature, wet bulb temperature, and relative humidity, where different instruments take measurements at both the suction and return paths of HVAC system. As such, the user interface shown in FIG. **3**B provides a technician with an overview of the state of the entire system in a single dashboard.

[0062] FIG. **3**C is a screenshot of a user interface of an application according to one embodiment of the present invention displaying a list of recent jobs, providing access to recorded data from measurements taken at the various jobs, and providing a mechanism to add a new customer site. FIG. **3**D is a screenshot of a user interface of an application according to one embodiment of the present invention displaying a list of sessions at a selected job site and an option to start a new session. FIG. **3**E is a screenshot of a user interface of an application according to one embodiment of the present invention displaying notes taken by a technician regarding their experience at a job site and providing an interface to load system parameters from a library (e.g., database) of known HVAC systems. FIG. **3**F is

a screenshot of a user interface of an application according to one embodiment of the present invention displaying a checklist of items to review at a particular job site, including system health indicators.

[0063] FIG. **4** is a block diagram of a computer server system according to one embodiment of the present invention. As shown in FIG. **4**, the computer server **300** includes a processor **310** and memory **320**. The memory stores instructions that, when executed by the processor **310**, cause the processor to perform various operations in accordance with embodiments of the present invention, as described in more detail below. The computer server **300** is connected to the network **200** and can communicate with the computing system **100** via the network **200** to receive, for example, the data from the HVAC test instruments **10**.

[0064] According to various embodiments of the present invention, the computer server **300** may be implemented directly on a physical processor and memory, virtualized as a virtual machine or as an operating-system-level virtual machine (e.g., a Docker® container, a FreeBSD Jail, or the like), or implemented using other systems for hosting application software. While the computer server **300** is described herein using the singular here, in some embodiments of the present invention, the functionality is spread or distributed and/or replicated among multiple physical computers which may be located in the same place (e.g., same data center) or different places (e.g., different data centers).

[0065] As discussed above, in some embodiments, the computer server **300** is configured to store the data from the on-site HVAC test instruments, received over the network, in the persistent data storage system or cloud database **350**. According to various embodiments of the present invention, the persistent data storage system **350** may be implemented using, for example, database software (e.g., MySQL®, Microsoft® SQL Server®, PostgreSQL, and the like), a key value store or NoSQL database (e.g., Redis®, MongoDB®, and the like), data files on a mounted volume (e.g., files on a network volume, with the data stored in formats such as Extensible Markup Language (XML), JavaScript Object Notation (JSON), and Comma Separated Value (CSV)), and the like. The computer server **300** may store an archive of all of the service history and the data collected across the plurality service jobs performed by the field technicians over time. This resulting archive may be used, for example, for internal auditing and overall performance monitoring, as well as for monitoring the improvement in proficiency of the individual technicians.

[0066] In some embodiments of the present invention, the computer server **300** is configured to communicate with the persistent data storage system or cloud database **350** through a data storage connection **325**, which is configured to convert the data into a format appropriate for storage in the configured storage format (e.g., a SQL database, a NoSQL database, in data files, etc.).

[0067] In some embodiments, the memory **320** of the computer server **300** also stores application processing logic **327** configured to control various operations of the computer server **300**. The application processing logic **327** may be implemented as a software program, such as a web application configured to present an application programming interface (API) (e.g., a Representational State Transfer or REST based API) to external client software such as an application running on the computing system **100**. In other embodiments, the application processing logic **327** is implemented in other parts of the computer server **300**, or in a separate computer server configured to control the computer server **300**.

[0068] FIG. **5** is a flowchart of a method for storing and analyzing data according to one embodiment of the present invention. Referring to FIG. **5**, in some embodiments of the present invention, the application processing logic **327** includes instructions to receive, in operation **51**, HVAC instrument data from the network **200** (e.g., from the computing system **100** on-site at the HVAC system). In operation **53**, the application processing logic **327** stores the received data in the persistent data storage system **350** using the data storage connection **325** to convert the data to the appropriate format for storage.

[0069] In operation **55**, the application processing logic **327** computes metrics based on data stored in the persistent data storage system **350**. While this data includes the data recently received from the on-site computing system **100**, the persistent data storage system **350** may also include reference data and/or historical data (e.g., measurement data received from other HVAC systems at other sites). Accordingly, the HVAC sensor measurements can be compared against measurements taken at other HVAC systems (e.g., other systems of comparable size). This can provide the HVAC technician with additional context for the measurements taken on-site and can provide information about portions of the on-site HVAC system that may require service or further analysis. Accordingly, in operation **57**, the application processing logic **327** transmits the computed metric over the network **200** to the on-site computing system **100** for display on the display device **140** and/or the smart glasses **130**.

[0070] As noted above, some aspects of embodiments of the present invention relate to the remote monitoring of the on-site conditions by a remote HVAC technician. FIG. **6**A is a block diagram of a remote computing system **400** according to one embodiment of the present invention. In various embodiments of the present invention, the remote computing system **400** may be a personal computing device such as a smartphone, a tablet computer, a laptop computer, a desktop computer, and the like. The remote computing system **400** may include a display device **410** for displaying information to the remote HVAC technician. In some embodiments of the present invention, the remote computing device includes multimedia hardware such as an audio device **420** (e.g., a speaker and/or headphones), a microphone **430**, and a camera **440**. The remote computing device may also include user input devices such as a keyboard, a mouse or other pointing device, and/or a touch sensitive panel (e.g., the display device **410** may be a touch sensitive display device).

[0071] FIG. **6**B is a screenshot of a user interface **600** of a remote monitoring application for dispatching technicians according to one embodiment of the present invention running on a remote computing system. As shown in FIG. **6**B, the user interface may show the locations and statuses of various technicians in a map **602**, along with the amount of time that each technician has spent at a job site. The user interface may also provide functionality to initiate a call with any given technician **604**, and to view a live session to monitor and to provide feedback to the technician, as discussed in more detail below.

[0072] FIG. **7**A is a flowchart of a method for displaying collected data on a remote computing device and providing

feedback in a live session according to one embodiment of the present invention. FIG. **7**B is a screenshot of a user interface **700** of a remote monitoring application for remotely monitoring a technician **702** according to one embodiment of the present invention running on a remote computing system. In operation **71**, the remote computing system **400** receives, via the network **200**, the HVAC instrument data captured by the on-site HVAC test instruments **10** and metrics computed from the measurements (computed by the on-site computing system **100** and/or the computer server **300**). In operation **73**, the remote computing system **400** displays the received HVAC instrument data and/or computed metrics in a dashboard portion **704** of the user interface **700**. The displayed data and metrics may be substantially similar or identical to the data available for display to the on-site HVAC technician as viewed using the on-site computing system **100**. Accordingly, the remote HVAC technician has access to the same information that the on-site HVAC technician has regarding the measured parameters of the on-site HVAC system. In addition, the user interface **700** may display graphs **706** of the recorded data captured over the course of the technician's visit to the site.

[0073] In operation **75**, the remote computing system **400** enables communication between the on-site HVAC technician and the remote HVAC technician. The communication may include audio and video communication (e.g., a videoconference) and can be conducted through the multimedia components (the audio device, the microphone, and/or the camera) of the computing devices **100** and **400** as well as through the user input devices (e.g., through a text chat interface) of the computing devices **100** and **400** so that the on-site and remote HVAC technicians can discuss their analyses of the HVAC system in view of the HVAC instrument data that is displayed to both HVAC technicians. For example, in some embodiments a live video stream **708** from the on-site HVAC technician is displayed in the user interface **700** of the remote system so that the remote HVAC technician can see what the on-site HVAC technician is seeing. In some embodiments, the video is stored by the computer server **300** and the remote HVAC technician can use a scrubbing bar (or other user interface control) to seek the recorded video to prior times. In some embodiments of the present invention, other types of communication can be provided such as direct screen sharing (e.g., of the screen shown on the remote computing system) or, in a more specialized case, the computing systems **100** and **400** can allow the annotation of portions of the measurements and metrics shown on the display device. As a more specific example, the remote HVAC technician and/or the on-site HVAC technician can annotate various portions of the graphs (e.g., using a virtual ink tool) and have the annotations be displayed to both parties, such that the on-site HVAC technician and the remote HVAC technician can easily discuss the data presented on their respective computing devices. As another specific example, the remote HVAC technician can annotate objects in the video (e.g., where individual objects may be automatically segmented from the environment and tracked by applying image segmentation algorithms as known in the art, such as applying a trained convolutional neural network), to draw the attention of on-site HVAC technician to particular objects or controls that are on-site. In some embodiments, the annotations of the objects are depicted to the on-site technician through an augmented reality (AR) feature implemented in the display device **140** of the on-site computing system **100** and/or in the smart glasses or goggles **130**.

[0074] The display of the data to the remote HVAC technician allows the remote HVAC technician to provide feedback, guidance, coaching, and/or a second opinion without requiring the on-site HVAC technician to, for example, speak all of the values of the various instruments to the remote HVAC technician over the phone. Furthermore, video data from the site of the HVAC system, as captured by, for example, the camera **134** of the smart glasses **130** or a camera integrated into the on-site computing system **100** (e.g., the camera of a smartphone) can be used to transmit images from the site to the remote HVAC technician, thereby allowing the remote HVAC technician to see what the on-site HVAC technician is seeing.

[0075] This sharing of information accelerates the diagnosing of problems and can allow the remote HVAC technician (who may be more experienced or who may be serving as a mentor or a coach, such as a mentor or a coach associated with a trade organization who is assisting an employee of a member company of the trade organization) to provide remote, live mentoring for training the on-site HVAC technician (who may be a more junior HVAC technician). The sharing of information can also be useful between peers, such as to get a second opinion on a situation. Furthermore, live video captured by the on-site HVAC technician can give the remote HVAC technician additional context to guide the on-site HVAC technician in taking additional measurements, analyzing problems, and developing solutions to improve the performance of the HVAC system.

[0076] In some embodiments of the present invention, potential remote HVAC technicians are connected with on-site HVAC technicians requesting consultations through a matchmaking system. For example, one or more remote HVAC technicians may register as being available for consultation. When an on-site HVAC technician requests a consultation, messages are sent to the available remote HVAC technicians, any one of which may respond to the request. In some embodiments of the present invention, the system automatically handles billing the requesting on-site HVAC technician and compensating the responding remote HVAC technician for the consultation, where the pricing may be set based on rates set, for example, by the remote HVAC technicians. In some embodiments, the requests include brief summaries on the nature of the consultation (e.g., type of building, nature of question, spoken language preferences, and the like). In some embodiments, the messages containing the consultation request are sent only to remote HVAC technicians meeting particular criteria (e.g., familiarity with particular HVAC systems, languages spoken, pricing, and the like). In some embodiments of the present invention, a requesting on-site HVAC technician is matched with a remote HVAC technician selected randomly from all available and qualified remote HVAC technicians registered with the system (e.g., satisfying criteria set in the request).

[0077] Some aspects of embodiments of the present invention relate to control of access to different types of metrics based on a user's subscription level to the data. For example, the software running on the on-site computing system **100** and/or the software running on the server computer **300** may include account information for the on-site HVAC technician and/or the remote HVAC technician and restrict access

to particular types of metrics based on the level of subscription to the service. For example, lower levels of subscription may provide only sufficient information for triaging an HVAC system and/or pressure diagnostics (e.g., relating to the efficiency of the duct work) whereas higher level subscriptions may provide access to airflow measurement information (velometer data) and whole building analysis (e.g., the effect of the whole house on the load of the system, such as insulation).

[0078] Some aspects of embodiments of the present invention relate to generating reports for customers (e.g., homeowners) to review based on the measurements captured by the HVAC test instruments **10**. For example, some automatically generated reports can provide information about the energy efficiency of the HVAC system before and after service by the HVAC technician.

[0079] Aspects of embodiments of the present invention may also be applied to performing analyses of HVAC systems for compliance with government regulations (such as building codes like the California Building Standards Code found in Title 24 of the California Code of Regulations and agency rules like California Energy Commission rules on building HVAC efficiency standards). According to some embodiments of the present invention, an inspector (such as a certified California Home Energy Rating System (HERS) rater) may use a collection of HVAC test instruments **10** and an on-site computing device n to collect data regarding an HVAC system (e.g., duct leakage and fan wattage draw). Because embodiments of the present invention enable the automatic collection and storage of data from HVAC test instruments that are placed in and around an HVAC system, embodiments of the present invention simplify the process of collecting and recording data and computing metrics by the inspector to determine whether the HVAC system complies with standards (e.g., HVAC efficiency standards) set by various rules and regulations.

[0080] While the present invention has been described in connection with certain exemplary embodiments, it is to be understood that the invention is not limited to the disclosed embodiments, but, on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims, and equivalents thereof.

1. A system for analyzing a heating, ventilation, and air conditioning (HVAC) system, comprising:

a processor;

a display device controlled by the processor;

a wireless communication module configured to receive a plurality of measurements from a plurality of different HVAC test instruments arranged to take measurements from the HVAC system, each of the HVAC test instruments providing one or more of the measurements; and

a memory having instructions stored thereon where, when the instructions are executed by the processor, cause the processor to:

receive the measurements from the different HVAC test instruments via the wireless communication module;

convert the measurements to a common format;

store the measurements in the common format in the memory;

compute one or more metrics based on the measurements, the one or more metrics comprising a superheat calculation relating to a refrigerant charge; and

display the computed one or more metrics including the superheat calculation relating to the refrigerant charge on the display device.

2. The system of claim **1**, wherein the plurality of different HVAC test instruments comprise at least two HVAC test instruments selected from:

a temperature sensor;

a velometer;

a balometer;

a manometer;

a pressure sensor; or

a multimeter.

3. (canceled)

4. The system of claim **1**, wherein the memory further stores instructions that, when executed by the processor, cause the processor to:

retrieve a plurality of previously stored measurements from the memory; and

display a plurality of line graphs of the previously stored measurements over time.

5. The system of claim **4**, wherein the memory further stores instructions that, when executed by the processor, cause the processor to:

compute one or more metrics over time based on the previously stored measurements; and

display one or more line graphs of the one or metrics computed based on the previously stored measurements.

6. The system of claim **1**, further comprising a network adapter,

wherein the memory further stores instructions that, when executed by the processor, cause the processor to:

transmit the measurements to a computer server via the network adapter;

receive one or more metrics from the computer server via the network adapter; and

display the one or more metrics on the display device.

7. The system of claim **1**, further comprising a network adapter,

wherein the memory further stores instructions that, when executed by the processor, cause the processor to:

transmit the measurements to a computer server via the network adapter;

establish a communication channel with a remote computer, the remote computer comprising a remote display device displaying the measurements; and

transmit audio and video via the communication channel.

8. The system of claim **7**, wherein the memory further stores instructions that, when executed by the processor, cause the processor to:

receive audio via the communication channel.

9. The system of claim **7**, wherein the memory further stores instructions that, when executed by the processor, cause the processor to:

receive, via the communication channel, an annotation corresponding to a measurement displayed on the display device; and

display the annotation on the display device.

10. The system of claim **1**, wherein the memory further stores instructions that, when executed by the processor, cause the processor to:

compare the measurements to one or more standards stored in the memory to compute a comparison; and

compute compliance with the one or more standards based on the comparison.

11. A method for analyzing a heating, ventilation, and air conditioning (HVAC) system at a site, comprising:

receiving, by an on-site computing system, a plurality of measurements from a plurality of different HVAC test instruments arranged to take measurements from the HVAC system, each of the HVAC test instruments providing one or more of the measurements via a wireless communication module;

converting, by the on-site computing system, the measurements to a common format;

storing, by the on-site computing system, the measurements in the common format in a memory of the on-site computing system;

computing one or more metrics based on the measurements, the one or more metrics comprising a superheat calculation relating to a refrigerant charge; and

displaying, on a display device of the on-site computing system, the computed one or more metrics including the superheat calculation relating to the refrigerant charge.

12. The method claim **11**, wherein the plurality of different HVAC test instruments comprise at least two HVAC test instruments selected from:

a temperature sensor;

a velometer;

a balometer;

a manometer;

a pressure sensor; or

a multimeter.

13. (canceled)

14. The method of claim **11**, further comprising:

retrieving a plurality of previously stored measurements from the memory; and

displaying a plurality of line graphs of the previously stored measurements over time.

15. The method of claim **14**, further comprising:

computing one or more metrics over time based on the previously stored measurements; and

displaying one or more line graphs of the one or metrics computed based on the previously stored measurements.

16. The method of claim **11**, further comprising:

transmitting the measurements to a computer server via a network adapter;

receiving one or more metrics from the computer server via the network adapter; and

displaying the one or more metrics on the display device.

17. The method of claim **11**, further comprising:

transmitting the measurements to a computer server via a network adapter;

establishing a communication channel with a remote computer, the remote computer comprising a remote display device displaying the measurements;

transmitting audio and video captured by the on-site computing device to the remote computer via the communication channel; and

receiving audio via the communication channel.

18. The method of claim **17**, further comprising:

receiving, via the communication channel, an annotation corresponding to a measurement displayed on the display device; and

displaying the annotation on the display device.

19. The method of claim **11**, further comprising:

comparing the measurements to one or more standards stored in the memory to compute a comparison; and

computing compliance with the one or more standards based on the comparison.

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