

Claims

1. A system for non-invasive sensing of an object having a volume with a surface and an internal region, comprising:
 - a non-invasive sensor including:
 - a heat flux sensor having one or more heat flux sensor output terminals;
 - a temperature sensor having one or more temperature sensor output terminals,
 - wherein the non-invasive sensor is adapted to be placed on or near the surface of the object, where the internal region of the object has internal properties indicated by corresponding internal parameters and an internal temperature distribution,
 - control circuitry, coupled to the one or more heat flux sensor output terminals and the one or more temperature sensor output terminals, to:
 - receive a measured temperature signal from the temperature sensor at one or more specified times;
 - receive a measured heat flux signal from the heat flux sensor at the one or more specified times;
 - determine a value for each of the internal parameters at the one or more specified times;
 - determine an internal temperature distribution of the internal region of the object at the one or more specified times based on the measured temperature signal, the measured heat flux signal, and the values of the internal parameters;
 - and
 - generate information indicating the internal temperature distribution of the internal region of the object at the one or more specified times.
2. The system in claim 1, wherein the control circuitry is configured to determine a measure of heat transfer leaving or entering the object at the surface based on the measured heat flux signal.
3. The system in claim 1, wherein the control circuitry is configured to generate information indicating one or more of the values determined for the internal parameters at the one or more specified times.
4. The system in claim 1, wherein the control circuitry is configured to determine the

internal temperature distribution of the internal region of the object at the one or more specified times based on the measured temperature signal, the measured heat flux signal, the values of the internal parameters, and one or more effects associated with an estimated thermal contact resistance between the temperature sensor and the surface of the object.

5. The system in claim 4, wherein the control circuitry is configured to generate the information generated indicating the internal temperature distribution of the internal region of the object at a specified time in less than one second from that specified time.

6. The system in claim 3, wherein the control circuitry is configured to generate the information generated indicating one or more of the values determined for the internal parameters at a specified time in less than one second from that specified time.

7. The system in claim 1, wherein the control circuitry is configured to use predetermined values for one or more of the internal parameters at specified times

8. The system in claim 1, wherein the control circuitry is configured to use estimated values for one or more of the internal parameters at specified times.

9. The system in claim 1, wherein the control circuitry is configured to:

determine estimated values for one or more of the internal parameters based on the measured temperature signal, the measured heat flux signal, and an estimated thermal contact resistance between the temperature sensor and the surface of the object.

10. The system in claim 9, wherein the control circuitry is configured to:

determine a calculated sensor temperature at the one or more specified times based on the measured temperature signal, the measured heat flux signal, the one or more estimated internal parameter values, one or more remaining internal parameter values when there are one or more remaining internal parameter values, and one or more effects associated with the estimated thermal contact resistance; and

compare the calculated sensor temperature with a measured temperature that is based on the measured temperature signal to determine a difference.

11. The system in claim 10, wherein the control circuitry is configured to:

adjust the values for one or more of the internal parameters and the estimated thermal contact resistance based on the difference to produce updated values of the internal parameters and the thermal contact resistance; and

determine the internal temperature distribution of the internal region of the object based on the measured temperature signal, the measured heat flux signal, and the updated values of the internal parameters and estimated thermal contact resistance.

12. The system in claim 10, wherein the control circuitry is configured to adjust the values for one or more of the internal parameters and the estimated thermal contact resistance to reduce the difference, and

wherein when the difference is less than a threshold amount or otherwise determined to be minimal, the values of the internal parameters and the value of the thermal contact resistance are at optimal updated values and the control circuitry is configured to generate information indicating the optimal updated values for the internal parameters and the thermal contact resistance.

13. The system in claim 10, wherein the control circuitry is configured to adjust the values of one or more of the internal parameters and the thermal contact resistance to reduce the difference using one or more optimization techniques.

14. The system in claim 10, wherein the control circuitry is configured to adjust the values of one or more of the internal parameters and the thermal contact resistance to reduce the difference using one or more machine learning techniques.

15. The system in claim 9, wherein the control circuitry is configured to determine the estimated value of the thermal contact resistance independent of the values of the internal parameters.

16. The system in claim 9, wherein the control circuitry is configured to determine the estimated value of the thermal contact resistance based on the values of the internal parameters.

17. The system in claim 9, wherein the control circuitry is configured to determine the estimated value of the thermal contact resistance based on a total steady-state thermal resistance of the object.

18. The system in claim 10, wherein the control circuitry is configured to adjust the

values of one or more of the internal parameters and the estimated thermal contact resistance in real-time to reduce the difference.

19. The system in claim 1, wherein the control circuitry is configured to determine an internal temperature distribution of the internal region of the object at the one or more specified times based on the measured temperature signal and the measured heat flux signal using one or more machine learning techniques.

20. The system in claim 1, wherein the control circuitry is configured to determine an internal temperature distribution of the internal region of the object at the one or more specified times using one or more thermal mathematical models for the object based on one or more surface heat flux boundary conditions.

21. The system in claim 20, wherein the thermal mathematical model has a transient temperature solution defined as a function of initial temperature distribution, heat flux, time, space, and the internal parameters.

22. The system in claim 20, wherein the thermal mathematical model includes one or more steady-state conditions.

23. The system in claim 21, wherein the initial temperature distribution is based on a steady-state temperature profile.

24. The system in claim 1, wherein the internal parameters include one or more from a list comprising:

- R'' : steady-state thermal resistance,
- x : depth from the surface,
- R''_{total} : total steady-state thermal resistance,
- U : overall heat transfer coefficient,
- k : thermal conductivity,
- ρ : density,
- C : heat capacity,
- ρC : volumetric heat capacity,
- $\sqrt{k\rho C}$: thermal inertia,
- $\alpha = \frac{k}{\rho C}$: thermal diffusivity,
- h : convection heat transfer coefficient,

$\dot{v}$: flowrate,
 δ : wall thickness,
 τ : time constant, and
 w : blood perfusion.

25. The system in claim 1, wherein the non-invasive sensor includes thermal insulation to reduce measured signal noise.
26. The system in claim 1, wherein the non-invasive sensor includes thermal insulation to control an amount of heat transfer occurring through the non-invasive sensor.
27. The system in claim 1, wherein the temperature sensor is a thin-film thermocouple, a thin temperature sensor, a resistance temperature sensor, or a fiber optic temperature sensor.
28. The system in claim 1, wherein the heat flux sensor is based on differential thermopile technology.
29. The system in claim 1, wherein the heat flux sensor is based on thin-film technology.
30. The system in claim 1, wherein the heat flux sensor is a thin heat flux sensor.
31. The system in claim 1, wherein the heat flux sensor is a flexible heat flux sensor.
32. The system in claim 1, wherein the heat flux sensor is based on one or more thermoelectric devices.
33. The system in claim 1, further comprising one or more external thermal devices for heating or cooling the non-invasive sensor.
34. The system in claim 1, wherein the control circuitry controls one or more external thermal devices for heating or cooling the non-invasive sensor.
35. The system in claim 1, wherein the control circuitry controls one or more external thermal devices for heating or cooling the non-invasive sensor to maintain a measured heat flux signal and/or temperature signal. .
36. The system in claim 1, wherein the temperature sensor is located on or near a heat flux sensor sensing area.
37. The system in claim 1, wherein the temperature sensor is between the object and heat flux sensor.
38. The system in claim 1, wherein the heat flux sensor is between the object and

temperature sensor.

39. A system for non-invasive sensing of an object having a volume with a surface and an internal region, comprising:

a non-invasive sensor including:

a heat flux sensor having one or more heat flux sensor output terminals;

a temperature sensor having one or more temperature sensor output terminals,

wherein the non-invasive sensor is adapted to be placed on or near the surface of the object, where the internal region of the object has internal properties indicated by corresponding internal parameters and an internal temperature distribution,

control circuitry, coupled to the one or more heat flux sensor output terminals and the one or more temperature sensor output terminals, to:

receive a measured temperature signal from the temperature sensor at one or more specified times;

receive a measured heat flux signal from the heat flux sensor at the one or more specified times;

determine estimated values for one or more of the internal parameters at the one or more specified times based on the measured temperature signal and the measured heat flux signal; and

generate information indicating one or more of the estimated values determined for the internal parameters at the one or more specified times.

40. The system in claim 39, wherein the control circuitry is configured to determine a measure of heat transfer leaving or entering the object at the surface based on the measured heat flux signal.

41. The system in claim 39, wherein the control circuitry is configured to include one or more effects related to an estimated thermal contact resistance between the temperature sensor and the surface of the object.

42. The system in claim 39, wherein the control circuitry is configured to:

determine the estimated values for one or more of the internal parameters at the one or more specified times based on the measured temperature signal, the measured heat flux signal, an estimated thermal contact resistance between the

temperature sensor and the surface of the object, and internal property values determined for one or more internal properties of the internal region of the object at the one or more specified times; and

generate information indicating at least one of the estimated values determined for the internal parameters.

43. The system in claim 39, wherein the control circuitry is configured to generate the information generated indicating one or more of the estimated values determined for the internal parameters at a specified time in less than one second from that specified time.

44. The system in claim 42, wherein the control circuitry is configured to generate the information generated indicating one or more of the estimated values determined for the internal parameters at a specified time in less than one second from that specified time.

45. The system in claim 42, wherein the control circuitry is configured to use predetermined values for one or more of the internal properties.

46. The system in claim 42, wherein the control circuitry is configured to use estimated values for one or more of the internal properties.

47. The system in claim 42, wherein the control circuitry is configured to:

determine a calculated sensor temperature at the one or more specified times based on the measured temperature signal, the measured heat flux signal, the one or more estimated internal parameter values, the one or more internal property values, and one or more effects associated with the estimated thermal contact resistance; and

compare the calculated sensor temperature with a measured temperature that is based on the measured temperature signal to determine a difference.

48. The system in claim 47, wherein the control circuitry is configured to adjust the values for one or more of the internal parameters and the estimated thermal contact resistance based on the difference to produce updated values of the internal parameters and the thermal contact resistance.

49. The system in claim 47, wherein the control circuitry is configured to adjust the values for one or more of the internal parameters and the estimated thermal contact resistance to reduce the difference, and

wherein when the difference is less than a threshold amount or otherwise determined to be minimal, the values of the internal parameters and the value of the thermal contact resistance are at optimal updated values and the control circuitry is configured to generate information indicating the optimal updated values for the internal parameters and the thermal contact resistance.

50. The system in claim 47, wherein the control circuitry is configured to adjust the values of one or more of the internal parameters and the thermal contact resistance to reduce the difference using one or more optimization techniques.

51. The system in claim 47, wherein the control circuitry is configured to adjust the values of one or more of the internal parameters and the thermal contact resistance to reduce the difference using one or more machine learning techniques.

52. The system in claim 41, wherein the control circuitry is configured to determine the estimated value of the thermal contact resistance independent of the values of the internal parameters.

53. The system in claim 41, wherein the control circuitry is configured to determine the estimated value of the thermal contact resistance based on the values of the internal parameters.

54. The system in claim 41, wherein the control circuitry is configured to determine the value of the estimated thermal contact resistance based on a total steady-state thermal resistance of the object.

55. The system in claim 47, wherein the control circuitry is configured to adjust the values of one or more of the internal parameters and the estimated thermal contact resistance in real-time to reduce the difference.

56. The system in claim 39, wherein the control circuitry is configured to determine the estimated values for one or more of the internal parameters based on the measured temperature signal and the measured heat flux signal using one or more machine learning techniques.

57. The system in claim 37, wherein the control circuitry is configured to determine the estimated values for one or more of the internal parameters using one or more thermal mathematical models for the object based on one or more surface heat flux boundary conditions.

58. The system in claim 57, wherein the thermal mathematical model has a transient temperature solution defined as a function of initial temperature distribution, heat flux, time, space, and the internal parameters.
59. The system in claim 57, wherein the thermal mathematical model includes one or more steady-state conditions.
60. The system in claim 58, wherein the initial temperature distribution is based on a steady-state temperature profile.
61. The system in claim 39, wherein the internal parameters include one or more from a list comprising:
- R'' : steady-state thermal resistance,
 - x : depth from the surface,
 - R''_{Total} : total steady-state thermal resistance,
 - U : overall heat transfer coefficient,
 - k : thermal conductivity,
 - ρ : density,
 - C : heat capacity,
 - ρC : volumetric heat capacity,
 - $\sqrt{k\rho C}$: thermal inertia,
 - $\alpha = \frac{k}{\rho C}$: thermal diffusivity,
 - h : convection heat transfer coefficient,
 - $\dot{v}$: flowrate,
 - δ : wall thickness,
 - τ : time constant, and
 - w : blood perfusion.
62. The system in claim 39, wherein the non-invasive sensor includes thermal insulation to reduce measured signal noise.
63. The system in claim 39, wherein the non-invasive sensor includes thermal insulation to control an amount of heat transfer occurring through the non-invasive sensor.
64. The system in claim 39, wherein the temperature sensor is a thin-film thermocouple, a thin temperature sensor, a resistance temperature sensor, or a fiber optic

temperature sensor.

65. The system in claim 39, wherein the heat flux sensor is based on differential thermopile technology.

66. The system in claim 39, wherein the heat flux sensor is based on thin-film technology.

67. The system in claim 39, wherein the heat flux sensor is a thin heat flux sensor.

68. The system in claim 39, wherein the heat flux sensor is a flexible heat flux sensor.

69. The system in claim 39, wherein the heat flux sensor is based on one or more thermoelectric devices.

70. The system in claim 39, further comprising one or more external thermal devices for heating or cooling the non-invasive sensor.

71. The system in claim 39, wherein the control circuitry controls one or more external thermal devices for heating or cooling the non-invasive sensor.

72. The system in claim 39, wherein the control circuitry controls one or more external thermal devices for heating or cooling the non-invasive sensor to maintain a measured heat flux signal and/or temperature signal.

73. The system in claim 39, wherein the temperature sensor is located on or near a heat flux sensor sensing area.

74. The system in claim 39, wherein the temperature sensor is between the object and heat flux sensor.

75. The system in claim 39, wherein the heat flux sensor is between the object and temperature sensor.

76. A system for non-invasive sensing of an object having a volume with a surface and an internal region, comprising:

- a first non-invasive, heat flux sensor-temperature sensor pair;

- a second non-invasive, heat flux sensor-temperature sensor pair;

- each of the first and second non-invasive, heat flux sensor-temperature sensor pairs including:

- a heat flux sensor having one or more heat flux sensor output terminals;

- a temperature sensor having one or more temperature sensor output terminals,

wherein the first and second non-invasive, heat flux sensor-temperature sensor pairs are adapted to be placed at different locations on or near the surface of the object, and where the internal region of the object has internal properties indicated by corresponding internal parameters and an internal temperature distribution,

control circuitry, coupled to the one or more heat flux sensor output terminals and the one or more temperature sensor output terminals of each of the first and second non-invasive, heat flux sensor-temperature sensor pairs, and configured to:

- receive a first measured temperature signal from the temperature sensor in the first non-invasive, heat flux sensor-temperature sensor pair at one or more specified times;

- receive a first measured heat flux signal from the heat flux sensor in the first non-invasive, heat flux sensor-temperature sensor pair at the one or more specified times;

- receive a second measured temperature signal from the temperature sensor in the second non-invasive, heat flux sensor-temperature sensor pair at one or more specified times;

- receive a second measured heat flux signal from the heat flux sensor in the second non-invasive, heat flux sensor-temperature sensor pair at the one or more specified times;

- determine a value for each of the internal parameters at the one or more specified times;

- determine an internal temperature distribution at the one or more specified times based on the measured temperature signals from the temperature sensors in the first and second non-invasive, heat flux sensor-temperature sensor pairs at the one or more specified times, the measured heat flux signals from the heat flux sensors in the first and second non-invasive, heat flux sensor-temperature sensor pairs at the one or more specified times, and the values of the internal parameters at the one or more specified times; and

- generate information indicating the internal temperature distribution at the one or more specified times.

77. The system in claim 76, wherein each respective temperature sensor is between

the object and its corresponding heat flux sensor.

78. The system in claim 76, wherein the control circuitry is configured to determine a measure of heat transfer occurring through the first non-invasive, heat flux sensor-temperature sensor pair and leaving or entering the object at the surface based on the first measured heat flux signal at the one or more specified times.

79. The system in claim 76, wherein the control circuitry is configured to determine a measure of heat transfer occurring through the second non-invasive, heat flux sensor-temperature sensor pair and leaving or entering the object at the surface based on the second measured heat flux signal at the one or more specified times.

80. The system in claim 76, wherein the control circuitry is configured to initially use predetermined values for the internal parameters.

81. The system in claim 76, wherein the control circuitry is configured to initially use estimated values for the internal parameters.

82. The system in claim 76, wherein the first and second non-invasive, heat flux sensor-temperature sensor pairs are subject to a differential heat flux environment.

83. The system in claim 76, wherein the control circuitry is configured to account for one or more effects associated with an estimated thermal contact resistance between the temperature sensor in the first non-invasive, heat flux sensor-temperature sensor pair and the surface of the object.

84. The system in claim 76, wherein the control circuitry is configured to account for one or more effects associated with an estimated thermal contact resistance between the temperature sensor in the second non-invasive, heat flux sensor-temperature sensor pair and the surface of the object.

85. The system in claim 76, wherein the control circuitry, is configured, in steady-state conditions, to:

determine the internal temperature distribution at the one or more specified times based on the measured temperature signals from the temperature sensors in the first and second non-invasive, heat flux sensor-temperature sensor pairs at the one or more specified times and the measured heat flux signals from the heat flux sensors in the first and second non-invasive, heat flux sensor-temperature sensor pairs at the one or more specified times.

86. A system for non-invasive sensing of an object having a volume with a surface and an internal region, comprising:

- a first non-invasive, heat flux sensor-temperature sensor pair;

- a second non-invasive, heat flux sensor-temperature sensor pair;

each of the first and second non-invasive, heat flux sensor-temperature sensor pairs including:

- a heat flux sensor having one or more heat flux sensor output terminals;

- a temperature sensor having one or more temperature sensor output terminals,

wherein the first and second non-invasive, heat flux sensor-temperature sensor pairs are adapted to be placed at different locations on or near the surface of the object, and where the internal region of the object has internal properties indicated by corresponding internal parameters and an internal temperature distribution,

control circuitry, coupled to the one or more heat flux sensor output terminals and the one or more temperature sensor output terminals of each of the first and second non-invasive, heat flux sensor-temperature sensor pairs, and configured to:

- receive a first measured temperature signal from the temperature sensor in the first non-invasive, heat flux sensor-temperature sensor pair at one or more specified times;

- receive a first measured heat flux signal from the heat flux sensor in the first non-invasive, heat flux sensor-temperature sensor pair at the one or more specified times;

- receive a second measured temperature signal from the temperature sensor in the second non-invasive, heat flux sensor-temperature sensor pair at one or more specified times;

- receive a second measured heat flux signal from the heat flux sensor in the second non-invasive, heat flux sensor-temperature sensor pair at the one or more specified times;

- determine an initial value for each of the internal parameters at the one or more specified times;

determine one or more internal parameters of the object at the one or more specified times based on the measured temperature signals from the temperature sensors in the first and second non-invasive, heat flux sensor-temperature sensor pairs at the one or more specified times and the measured heat flux signals from the heat flux sensors in the first and second non-invasive, heat flux sensor-temperature sensor pairs at the one or more specified times, and the initial values of the internal parameters at the one or more specified times; and

generate information indicating one or more internal parameters of the object at the one or more specified times.

87. The system in claim 86, wherein the control circuitry is configured to determine a measure of heat transfer occurring through the first non-invasive, heat flux sensor-temperature sensor pair and leaving or entering the object at the surface based on the first measured heat flux signal at the one or more specified times.

88. The system in claim 86, wherein the control circuitry is configured to determine a measure of heat transfer occurring through the second non-invasive, heat flux sensor-temperature sensor pair and leaving or entering the object at the surface based on the second measured heat flux signal at the one or more specified times.

89. The system in claim 86, wherein each respective temperature sensor is between the object and its corresponding heat flux sensor.

90. The system in claim 86, wherein the control circuitry is configured to initially use predetermined values for the internal parameters.

91. The system in claim 86, wherein the control circuitry is configured to initially use estimated values for the internal parameters.

92. The system in claim 86, wherein the first and second non-invasive, heat flux sensor-temperature sensor pairs are subject to a differential heat flux environment.

93. The system in claim 86 wherein the control circuitry is configured to account for one or more effects associated with an estimated thermal contact resistance between the temperature sensor in the first non-invasive, heat flux sensor-temperature sensor pair and the surface of the object.

94. The system in claim 86 wherein the control circuitry is configured to account for one or more effects associated with an estimated thermal contact resistance between the

temperature sensor in the second non-invasive, heat flux sensor-temperature sensor pair and the surface of the object.

95. The system in claim 86, wherein the control circuitry, is configured, in steady-state conditions, to:

determine one or more internal parameters of the object based on the measured temperature signals from the temperature sensors in the first and second non-invasive, heat flux sensor-temperature sensor pairs at the one or more specified times and the measured heat flux signals from the heat flux sensors in the first and second non-invasive, heat flux sensor-temperature sensor pairs at the one or more specified times.

96. A non-invasive sensor adapted to be placed on or near a surface of an object having a volume with an internal region, where the internal region of the object has internal properties indicated by corresponding internal parameters and an internal temperature distribution, the non-invasive sensor comprising:

a non-invasive, heat flux sensor-temperature sensor pair;

the non-invasive, heat flux sensor-temperature sensor pair including:

a heat flux sensor having one or more heat flux sensor output terminals to provide a measured heat flux signal for the surface of the object, and

a temperature sensor having one or more temperature sensor output terminals to provide a measured temperature signal for the surface of the object,

wherein the heat flux sensor and temperature sensor are configured to be subject to the same thermal conditions.

97. The non-invasive sensor in claim 96, further comprising one or more external thermal devices for heating or cooling the non-invasive sensor.

98. The non-invasive sensor in claim 97, wherein the one or more external thermal devices include a heater or a cooler.

99. The non-invasive sensor in claim 96, wherein the heat flux sensor is arranged to produce a differential voltage indicative of heat transfer occurring through the heat flux sensor at the object surface.

100. The heat flux sensor in claim 99, wherein the differential voltage is related to the heat transfer occurring through the heat flux sensor and at the object surface by a calibration constant or a sensitivity constant associated with the heat flux sensor.

101. The heat flux sensor in claim 99, wherein the differential voltage is related to the heat transfer occurring through the heat flux sensor and at the object surface by a calibration curve or a sensitivity curve associated with the heat flux sensor.
102. The non-invasive sensor in claim 96, wherein the heat flux sensor is based on thin-film differential thermopile technology.
103. The non-invasive sensor in claim 96, wherein the heat flux sensor includes two or more thermocouple junctions connected in series to provide a voltage output that is indicative of a temperature difference across a given thermal resistance.
104. The non-invasive sensor in claim 96, wherein the temperature sensor is based on thermocouple or thermistor technology.
105. The non-invasive sensor in claim 96, wherein a thickness of the temperature sensor is less than or equal to a thickness of the heat flux sensor.
106. The non-invasive sensor in claim 96, wherein the heat flux sensor is of the kind described by ASTM Standard E2683.
107. The non-invasive sensor in claim 96, wherein the heat flux sensor is of the kind described by ASTM Standard E2684.
108. A non-invasive sensor adapted to be placed on or near a surface of an object having a volume with a surface and an internal region, the non-invasive sensor comprising:
- a first non-invasive, heat flux sensor-temperature sensor pair;
 - a second non-invasive, heat flux sensor-temperature sensor pair;
 - each of the first and second non-invasive, heat flux sensor-temperature sensor pairs including:
 - a heat flux sensor having one or more heat flux sensor output terminals;
 - a temperature sensor having one or more temperature sensor output terminals,
 - wherein the first and second non-invasive, heat flux sensor-temperature sensor pairs are adapted to be placed at different locations on or near the surface of the object, where the internal region of the object has internal properties indicated by corresponding internal parameters and an internal temperature distribution.
109. The non-invasive sensor in claim 108, further comprising one or more external

thermal devices for heating or cooling the first non-invasive, heat flux sensor-temperature sensor pair.

110. The non-invasive sensor in claim 108, further comprising one or more external thermal devices for heating or cooling the second non-invasive, heat flux sensor-temperature sensor pair.

111. The non-invasive sensor in claim 108, wherein each of the heat flux sensors in the first and second non-invasive, heat flux sensor-temperature sensor pairs are arranged to produce a differential voltage indicative of heat transfer occurring through the first and second non-invasive, heat flux sensor-temperature sensor pairs, respectively.

112. The heat flux sensors in claim 111, wherein the differential voltage produced by each of the heat flux sensors in the first and second non-invasive, heat flux sensor-temperature sensor pairs are related to the heat transfer occurring through a corresponding heat flux sensor-temperature sensor pair by a calibration constant or a sensitivity constant associated with the heat flux sensor.

113. The heat flux sensors in claim 111, wherein the differential voltage produced by each of the heat flux sensors in the first and second non-invasive, heat flux sensor-temperature sensor pairs are related to the heat transfer occurring through a corresponding heat flux sensor-temperature sensor pair by a calibration curve or a sensitivity curve associated with the heat flux sensor.

114. The non-invasive sensor in claim 108, wherein the heat flux sensors are based on thin-film differential thermopile technology.

115. The non-invasive sensor in claim 108, wherein the heat flux sensors include two or more thermocouple junctions connected in series to provide a voltage output that is indicative of a temperature difference across a given thermal resistance.

116. The non-invasive sensor in claim 108, wherein the temperature sensor is based on thermocouple or thermistor technology.

117. The non-invasive sensor in claim 107, wherein a thickness of the temperature sensor is less than or equal to a thickness of the heat flux sensor.

118. The heat flux sensors in claim 108, wherein the heat flux sensor is of the kind described by ASTM Standard E2683.

119. The heat flux sensors in claim 108, wherein the heat flux sensor is of the kind

described by ASTM Standard E2684.