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[54] **FOUNDATION FOR CONSTRUCTION ON FROZEN SUBSTRATA**

[75] Inventors: **Glenn R. Burt**, Deer Park, Tex.; **Albert C. Condo**, Newtown Square, Pa.; **Richard L. Odsather**, Fairbanks, Alaska; **Kay E. Eliason**, Fort Madison, Iowa

[73] Assignee: **Atlantic Richfield Company**, New York, N.Y.

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[52] **U.S. Cl.** .... **165/45**, 52/169, 61/36 A, 61/50, 62/260, 98/1, 166/DIG. 1, 220/18, 61/50;36 A, 52/169, 62/260, 98/1, 220/18;9 LG, 166/DIG. 1

[51] **Int. Cl.** **E02d 3/00**

[58] **Field of Search** 165/45

[56] **References Cited**

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Primary Examiner—Albert W. Davis, Jr.
Assistant Examiner—S. J. Richter
Attorney, Agent, or Firm—Coleman R. Reap

[57] **ABSTRACT**

A foundation construction, particularly useful for buildings and other supported structures in Arctic regions wherein a permafrost condition typically prevails, is provided by a construction pad having at least one or more perforated and ventilated conduits positioned within a cushion of air-permeable particulate material, said cushion containing the perforated conduit being substantially thermally isolated from the supported structure by means such as encapsulating with an insulating material. Generally, the pad is overburdened with, or imbedded in, a suitable gravel fill material. The pad can substantially reduce, and in certain instances eliminate, the necessity of providing piling supports in Arctic regions and furthermore provides both a thermal barrier restricting heat flowing downward from the building to the frozen substrata and a type of thermal shunt blocking heat from the structure while admitting a certain amount of geothermal heat flowing upward from the ground to an ambient air heat sink.

19 Claims, 6 Drawing Figures

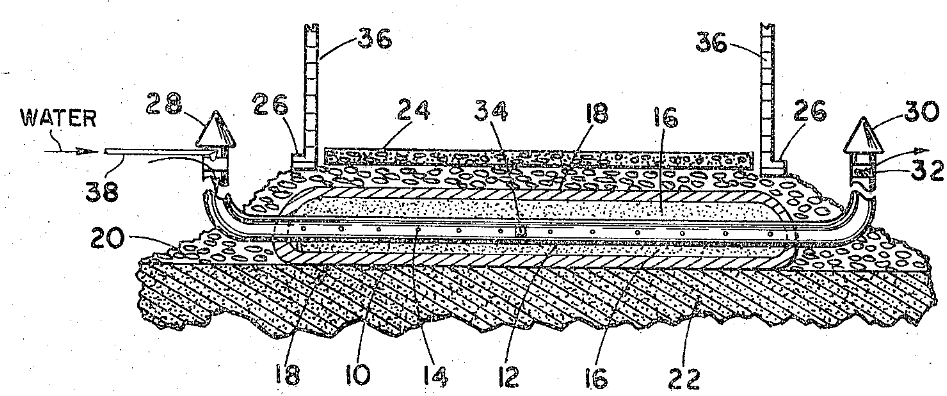


FIG.1

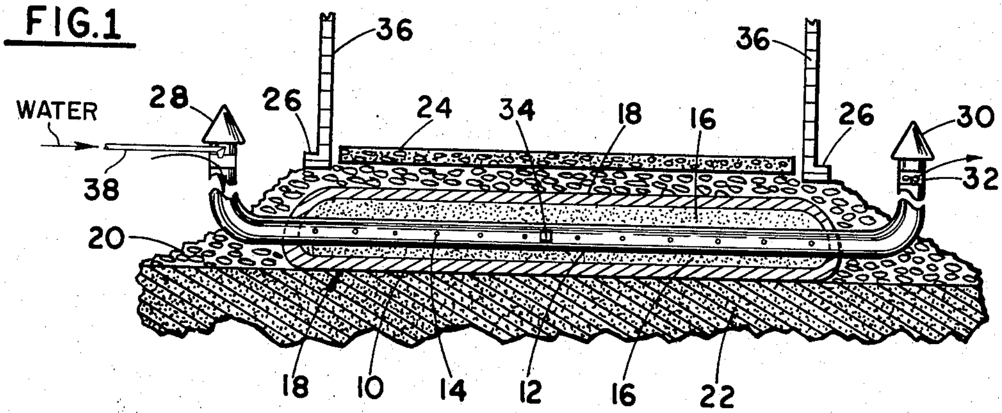
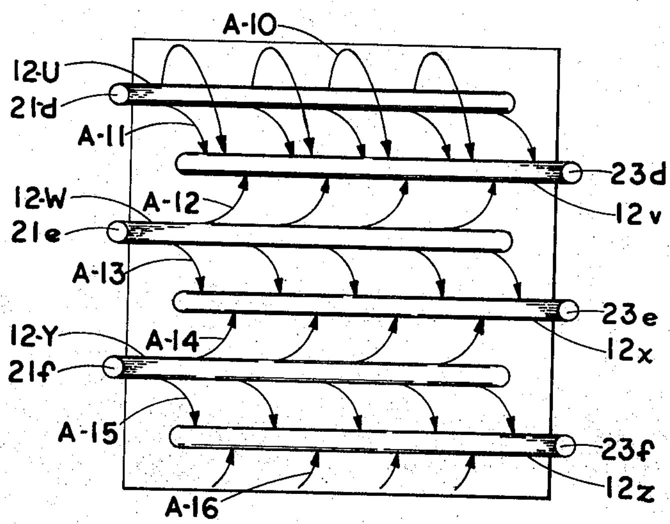
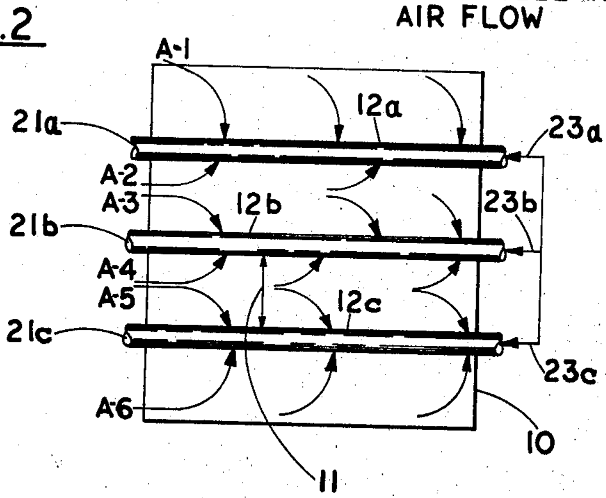


FIG.3



ARROWS IN PARALLEL INDICATE AIR FLOW

FIG.2



INVENTORS
GLENN R. BURT
RICHARD L. ODSATHER
KAY E. ELIASON
ALBERT C. CONDO

FIG. 4

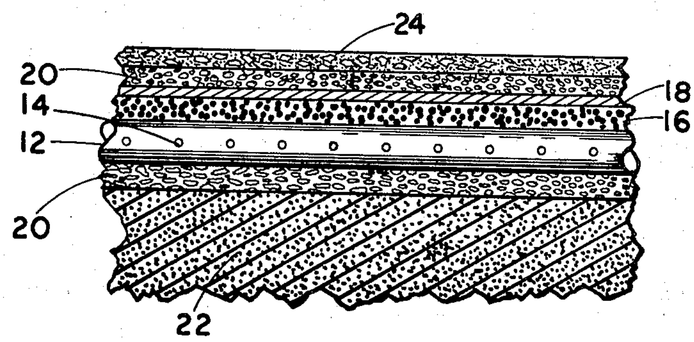


FIG. 5

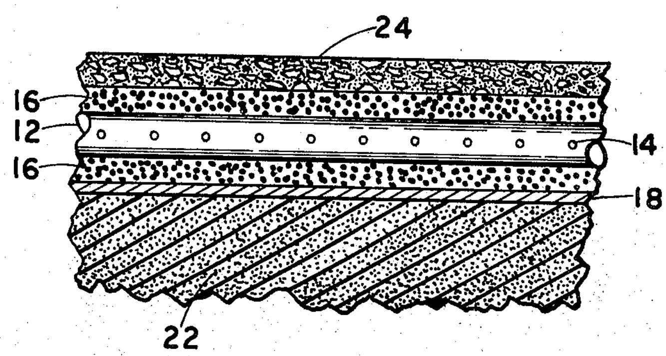
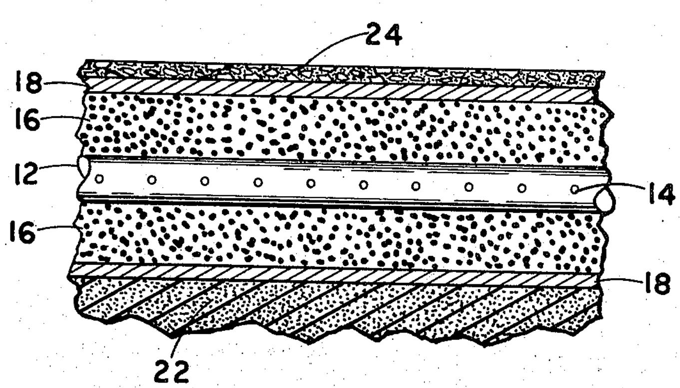


FIG. 6



INVENTORS
GLENN R. BURT
RICHARD L. ODSATHER
KAY E. ELIASON
ALBERT C. CONDO

FOUNDATION FOR CONSTRUCTION ON FROZEN SUBSTRATA

BACKGROUND OF THE INVENTION

Regions of the Arctic and sub-Arctic wherein perpetually frozen ground starts a few feet below the surface and extends downwardly are generally referred to as permafrost regions. Permafrost is permanently frozen ground and consists of mixtures of varying content of water, salt, sand and gravel. At the ground surface there is an active growth layer called the tundra which covers the permafrost and in the spring and summer thawing occurs to varying depths ranging from a few inches to several feet in an area between the tundra mat and permafrost zone which is called the "active layer." Thaw converts the tundra and active layer into a soggy marsh having minimal load bearing value. Thus, any foundation will displace the mud causing the building structure to either sink or become unstable.

Generally, foundations for such building structures as well as storage tanks, boiler houses and power plants are supported on the permafrost by pilings of steel or timber. The pilings are necessary to avoid excessive settlement caused by repeated thawing and subsequent subsidence of the Arctic substrata. However, installation of pilings not only requires a substantial investment but pilings may not adequately protect the building from the vagaries of the active layer such as frost-heave or "pole-jacking" due to freezing and thawing. Therefore, a more economical and efficient method for constructing building foundations would be an important contribution to the technology of coping with the climate variations of northern regions where a permafrost condition prevails.

It is known in the building of structures in permafrost regions that the foundation of the structures may be laid on gravel pads or sills. However, a gravel pad tends to function as too good a thermal conductor by permitting heat from the building floor to reach the permafrost substrata and conversely the temperature of the permafrost will be conducted upwardly toward that of the building floor. Therefore, a gravel pad, by itself, fails to completely eliminate the cycle of heaving and settlement resulting from seasonal freezing and thawing and subsidence due to permafrost destruction.

It is also known to place an insulating layer at some point between the building floor and the permafrost substrata; however, an insulating layer does not permit selective temperature control at the insulating layer environment such as to impede heat-input to the frozen substrata. Furthermore, an insulating layer functioning as the sole thermal barrier would be of substantial thickness and therefore economically expensive to install as well as be technically unsuitable. Likewise, other high thermal impedance systems such as gravel are similarly disadvantageous.

SUMMARY OF THE INVENTION

It is an object of this invention to provide a foundation construction particularly useful as a foundation for building structures in northern regions wherein a permafrost condition typically prevails. It is another object of this invention to provide a method of constructing a building foundation that will substantially reduce or eliminate the necessity of placing buildings on pilings. It is still another object of this invention to provide a foundation construction having a thermal barrier between the structure and the frozen substrata restricting heat flowing downward from the structure to the frozen substrata and providing a thermal shunt blocking heat from the structure while admitting some geothermal heat flowing upward from the permafrost substrata to an ambient air heat sink. A still further object of the invention is to provide an efficient and simplified thermal barrier that may be employed in construction in northern regions such as the Arctic and sub-Arctic

These and other objects of the invention are accomplished by providing a thermal barrier between the structure and the substrata comprising at least one perforated and ventilated conduit positioned within a cushion of air-permeable particulate material, said cushion and perforated conduit being substantially thermally isolated from the ambient atmosphere by encapsulation within an insulation material. If desired, the conduit system may comprise communicating pairs of inlet and outlet conduits.

DESCRIPTION OF THE INVENTION

The advantages of the invention will become more apparent from the following description considered in conjunction with the accompanying drawings wherein:

FIG. 1 is a cross section view of the foundation construction illustrating one embodiment of the invention;

FIG. 2 is a plan view of one variation of conduit arrangement within the cushion of particulate material;

FIG. 3 is another plan view illustrating the communicating pair arrangement of the conduits within the cushion of particulate material;

FIG. 4 is a fragmentary cross section view of a second embodiment of the foundation construction in accordance with the present invention;

FIG. 5 is a fragmentary cross section view of a third embodiment of the foundation construction in accordance with the present invention; and

FIG. 6 is another fragmentary cross section view of a fourth embodiment of the foundation construction.

Before giving detailed descriptions of the various views of the drawings, briefly stated in the foundation construction of the present invention requires a barrier that is thermally isolated from ambient air being, generally, in the form of a pad containing a perforated and ventilated conduit system embedded in a cushion of air-permeable particulate material wherein the perimeter of the pad is isolated from ambient air by encapsulation. Generally, the ventilated and perforated conduit system draws air from an inlet source through the conduits by mechanical means such as an exhaust fan to an outlet point while the perforations permit air within the thermally isolated cushion of air-permeable particulate material to also be drawn to the conduit outlet.

The perforated and ventilated conduit system is an essential feature of the invention and provides the means to move air within the air-permeable particulate material. For instance, during colder periods, ventilating means such as an exhaust fan placed at the outlet point of the conduit can be operated to draw cold ambient air through the particulate material and exhaust warm air transferred from the building floor to the cushion of particulate material. Therefore, the pad provides a means to intercept warm air flowing from the building floor toward the frozen substrate and dissipate it by conducting the air to the outer ambient "heat sink." At times when the ambient air is warmer than the desired temperature within the pad, the system may be shut down. Therefore, the pad functions in a different manner than mere insulation material that is incapable of dissipating heat but only serves to retard its passage to some degree.

Another essential feature of the invention is to provide means of thermal isolation of the pad from the ambient atmosphere in order to permit the pad to function as a thermal barrier so that temperatures within the pad are controllable. The pad may be thermally isolated by such means as encapsulation with an insulating material or by combinations of encapsulating means utilizing insulating material, gravel, sand, the building itself, frozen substrata, or other suitable barrier materials as will be described in greater detail hereinafter.

Referring now in greater detail to the various views of the drawings, in cross section view FIG. 1 thermally isolated pad **10** comprises perforated and ventilated conduits **12** horizontally spaced and containing perforations **14** and wherein the conduits are cushioned on screened particulate material **16.** For purposes of this invention the term "particulate material" designates air-permeable granules in the form of discrete particles as opposed to a mass of fines. Substantially all particles of air-permeable particulate material will have a diameter greater than the diameter of the perforations of the conduit to prevent clogging of the conduit with particulate material. However, small amounts of fines may be present in the particulate material to provide stability in the cushion. Suitable particulate material include screened gravel, crushed rock, pulverized concrete, and the like. The cushion of air-permeable particulate material **16** and the perforated portions of conduits **12** are encapsulated with insulation layer **18** to provide thermal isolation from the ambient air. Those portions of the conduit exposed to the ambient environment and/or are otherwise outside of the thermal barrier are solid (i.e., not perforated). Pad **10** is overburdened with granular fill material **20** that may be any conventionally used fill of any desired particle size used for base construction of buildings, roads, etc., such as gravel, crushed rock, sand and the like.

Ventilators **28** and **30** are provided at the conduit extremities to permit passage of air through the conduit. Motorized fans or blower arrangements **32** pull air into inlet ventillator **28** and through conduit **12** to exhaust ventilator **30.** The fans or blowers may be provided with temperature control means such as thermostat **34** to actuate the blower arrangement whenever it is necessary to dissipate heat build-up or otherwise alter the temperature within the pad.

Pat **10** is positioned beneath building floor **24** and rests on frozen substrata **22.** Building floor **24** may be concrete, wood, metal or any suitable flooring material and rests on the granular fill material **20.** Building load bearing supports **26** may also be of any suitable construction material as well as building walls **36.**

Preferably, insulation layer **18** is a rigid synthetic foam insulating material such as any of the polyurethanes or polystyrenes capable of supporting a load in low temperature applications without over-compressing or otherwise interfering with the thermal insulation properties. The thickness of the insulating pad may vary according to such parameters as the type of the insulating material used, the building design, environmental conditions, and the nature of the pad. Insulation thickness may be calculated from known equations which consider such variables as conductivity of the insulation, conductivity of the ground surface, thermal history of ambient air and temperature of the ground surface. Synthetic polymeric foams such as polyurethane specifically designed for low temperature environments are particularly desirable. However, other insulating means to provide the thermal barrier such as conventional inorganic materials including asbestos, fiberglass, insulating concrete block and the like could be employed for a portion or all of the insulation depending upon the building design and environmental conditions.

FIGS. **2** and **3** are fragmentary views illustrating various placements of the conduits within pad **10.** In FIG. 2 conduits **12***a*, **12***b*, and **12***c* are distributed at longitudinally spaced intervals **11** with each conduit having an air intake **21***a*, **21***b* and **21***c* and an air exhaust **23***a*, **23***b* and **23***c*. However, if desired, all or a portion of the air intakes may be connected to a common air intake and likewise all or a portion of the air exhausts may be connected to a common air exhaust. The particular longitudinal spacing **11** arrangement of the conduits or a desired vertical spacing may depend upon the nature of the particulate material, the size of the foundation, the temperature within the building, properties of the insulation, as well as other environmental considerations. Arrows A–1 through A–6 generally illustrate the air flow path within the thermally isolated pad and particularly illustrate that the voids within the particulate material permit air circulation within the thermally isolated pad.

FIG. **3** is another fragmentary view of the thermally isolated pad illustrating a conduit system wherein individual conduits are employed for air intake and individual conduits employed for air exhaust. Conduits **12***u*, **12***v*, **12***w*, **12***x*, **12***y* and **12***z* are longitudinally spaced within the cushion of particulate material. Conduits **12***u*, **12***w*, and **12***y* function as air intakes at **21***d*, **21***e* and **21***f*. Conduits **12***v*, **12***x* and **12***z* function as exhaust means at **23***d*, **23***e*, and **23***f*. For foundations of larger buildings the conduit placement of FIG. 3 may be desirable to provide improved air circulation within the thermally isolated pad. Although the FIG. 3 conduits illustrate a horizontal arrangement, the conduits may be independently spaced vertically and horizontally within the air-permeable particulate material. Arrows A–10 through A–16 generally indicate the air flow path within the pad. If desired, the air intake points may be commoned as well as air exhaust points.

FIGS. **4**, **5**, and **6** illustrate alternative means of providing the thermal isolation for the pad. In FIG. **4** the fragmentary view illustrates a system similar to FIG. **1** with the exception the insulating layer between conduit **12** and frozen substrata **22** is omitted. In this embodiment thermal isolation beneath the conduit is provided by the combination of granular fill material and frozen substrata. Suitable thermal isolation means are provided at the sides of the pad and insulating layer **18** is a thermal barrier above the pad.

FIG. **5** is similar to FIG. **4** but in this embodiment the separate insulation material above the conduit was omitted so that the insulating layer is provided by the building floor. Suitable insulating means substantially enclose the sides of the pad.

FIG. 6 is similar to FIG. 1 with the exception that the granular fill material was omitted so that the thermally isolated pad provides the entire foundation beneath the building.

In a preferred embodiment of this invention, the foundation construction is generally provided in the following manner. If the pad will be substantially encapsulated with a synthetic foam insulating material, a layer of insulation will be placed on the ground surface occupied by the proposed pad and then a layer of appropriate particulate material sufficient to support the conduit system placed on the insulation. After determining the pattern of placing the conduit system, i.e., to longitudinally and/or vertically space or a combination of both, the conduit system is laid and additional particulate material embeds the conduit system to provide the cushion. Then the remainder of the pad may be enclosed with insulation material to provide a thermal barrier obtained by an encapsulated layer of insulation. Installation of ventilating means such as motorized fans will pull the air from an inlet source to an exhaust point. The pad may be overburdened with appropriate granular fill material conventionally used as a base for building foundations, roadways, etc.

For purposes of this invention the term "thermally isolated" means that the cushion of air-permeable particulate material and perforated conduits, together with any required barrier material, create a thermal barrier so that substantially no significant uncontrolled amount of ambient air is permitted to enter the barrier, except that controlled amount entering the air intake distribution system, unless so desired. Although thermal isolation is generally obtained by an encapsulating layer of insulation material, in some instances the building floor, frozen substrata, etc., provide a portion of the thermal barrier. In addition to synthetic foams, other inorganic insulating materials such as insulated concrete block, insulating boards, etc., may be used, in whole or in part, to provide a thermal barrier.

In instances wherein the insulating material possesses water-absorbing properties, it is desirable to provide a hydrophobic or water impermeable layer to the foundation substrate. Generally, this hydrophobic barrier layer or "precoat" would be applied while warm and thereafter a layer of polyurethane foam may be spray applied to the warm surface. The thickness of the barrier layer may be in the range of from about 5 mils to 30 mils.

If the particular insulating material is a synthetic polymeric film such as a polyurethane, it is preferred to spray apply the foam in layers of about 3 to 8 per inch. In applying successive superimposed layers of foam to obtain cohesion between the layers, time should be allowed for the formation of a skin so that it is uniform and free from discontinuities before the next layer is applied. In order to get chemical bonding and consequently greater cohesion and strength, it is preferred to apply the next layer of foam before the skin layer on the layer of foam below has completely cured. In general, the next layer of foam should be applied within 1/2 to 30 minutes after the layer below it has completed foaming. This permits the lower skin layer to be completely formed without being completely cured and at the same time allows for variations in temperature.

In the construction of a warehouse building in the Prudhoe Bay area of the Arctic on a frozen substrata wherein the area of the building floor measures approximately 60 feet by 80 feet, a foundation pad for the building is provided as follows: A bituminous moisture barrier coating a petroleum residuum containing polyethylene is applied to an area of approximately 65 feet by 85 feet and thereafter about 1½ inches of a rigid polyurethane foam designed for low temperature application is applied with a spray foam machine using dichlorodifluoromethane as the blowing agent. Generally, any lower layer of insulation will extend beyond the building perimeter so that any thaw under the edge of the insulation does not proceed too closely to the direct load of the building. The foam has the following physical properties: A thermoconductivity of 0.13 BTU/Hr./Ft.^{2}/°F./In. (k factor at 77° F. as determined by ASTM-D-2326-64T using the probe method), a compression strength at yield of 43–50 psi, and an over-all density of 2.7 lbs./ft.^{3} (as determined by ASTM-D-1622-63).

Thereafter, Prudhoe Bay area gravel screened to remove particles of a size smaller than about 1/16 inch is placed over the entire foamed area to a depth of about 12 inches. Three aluminum perforated conduits each having a diameter of 10 inches are horizontally spaced from each other on the screened gravel. The size of the perforations of the concrete conduit are about 1/16 inch or smaller and the amount of perforated surface area of the conduit is about 5 percent. Thereafter, additional screened particulate material is poured over the duct so that the crown of the conduits are overburdened with about 12 inches of screened gravel. Using the same spray foam machine and the same polyurethane insulating material, a layer of foam about 2 to 4 inches in thickness applied in successive superimposed layers of about 5 per inch is placed over the entire exposed screened gravel surface on the top and sides and, together with the previously applied lower layer of foam, a thermal barrier is provided. Ventilators and appropriate fans or blowers are installed together with an optional fan control system such as a thermostat designed to actuate the fans when the temperature inside the thermal barrier is warmer than the outside ambient air. The thermal barrier pad is now covered with about 1 foot of granular fill material to provide a complete foundation without the necessity of pilings; however, piling may be provided as supplemental foundation means at high load-bearing areas.

During warmer months in the northern regions when the temperature of the ambient air exceeds the temperature within the thermal barrier, it may be desirable to provide a refrigeration effect. One method of accomplishing this is by an atomizer water spray system to provide evaporative cooling. Such a system 38 may be provided at the air inlet of the conduit as shown in FIG. 1 and would function to conduct water saturated air through the pad. Such air moving through the conduit by forcing means such as an exhaust or blower system produces evaporation of the atomized moisture and a resulting refrigeration effect so that the temperature within the encapsulated pad would be significantly below the inlet ambient air temperature. When the ambient air temperature reaches a point where it exceeds the desired temperature within the encapsulated pad, the motorized exhaust or blower system will automatically shut off if a thermostat is employed; however, the aforementioned atomizer water spray system would provide additional cooling means to dissipate heat from the thermal barrier pad.

As another alternative system to provide additional cooling within the encapsulated pad during warmer periods, the entire conduit system may be closed and connected to a heat exchanger unit to provide further control of the temperature within the pad.

Although this invention may obviate the necessity of pilings, in certain instances wherein the building load is concentrated at a particular point(s), it may be desirable to supplement the foundation construction of this invention with timber, concrete or steel pilings.

The moisture barrier coating is generally a bituminous composition, but other materials may be employed, such as plastic films and the like that act to separate surface moisture from any applied synthetic foams. Preferred as the moisture barrier is a crude oil residuum that may be extended with a synthetic polymeric material such as a low molecular weight polyethylene or styrene-butadiene rubber.

The aforementioned conduit systems were described as being independently horizontally spaced; however, depending upon the height of the pad, it may be desirable to horizontally and vertically space the conduits or employ one or more conduits wherein each winds a tortuous path within the thermal barrier. Similarly, branched pipeline systems may be designed. Fluid flow metering systems have been established for branching pipeline systems so that equal pressures and volumes can be controlled by determining the intake opening from the initial distribution system. Thus conduits located at increasing distances from the source will receive the same pressure and volume as those nearest the source.

Although the foundation construction of this invention is primarily intended for structures such as buildings, it may also be employed, either alone or together with pilings, as the foundation for drill rigs, water storage facilities, fuel storage bladders, pipelines, exposed storage areas, and the like.

Reasonable variations and modifications are possible within the scope of this invention without departing from the spirit and scope of the claims.

We claim:

1. A thermal barrier capable of being employed in Arctic region construction comprising at least one perforated and ventilated conduit positioned within a cushion of air-permeable load-bearing particulate material wherein said particulate material is substantially completely encapsulated with synthetic insulating load-bearing material from ambient environment.

2. The thermal barrier of claim **1** wherein said conduit is at least one pair of air conduits arranged to provide an air inlet conduit and a separate air outlet conduit.

3. The thermal barrier of claim **1** wherein said insulating material is a synthetic polymeric foam.

4. The thermal barrier of claim **3** wherein said synthetic polymeric foam is a polyurethane.

5. The thermal barrier of claim **1** having means to provide evaporative cooling within the thermal barrier.

6. The thermal barrier of claim **5** wherein evaporation cooling is provided by a water spray system at the air inlet of the conduit.

7. A foundation construction, useful in Arctic regions wherein a permafrost condition typically pervails, capable of providing a thermal barrier between a structure and the substrata comprising a pad having at least one perforated and ventilated conduit positioned within a cushion of air-permeable particulate material, said cushion and perforated conduit being substantially completely encapsulated by synthetic insulating material.

8. A foundation construction according to claim **7** wherein said pad is encapsulated with a foamed polyurethane insulating material.

9. A foundation construction according to claim **7** wherein said structure is a building.

10. A foundation construction according to claim **7** wherein said substrata is a frozen substrata.

11. A foundation construction according to claim **7** having mechanical means for forcing air through the perforated conduits.

12. A foundation construction according to claim **7** wherein said insulation material is synthetic foam.

13. A foundation construction according to claim **12** wherein said synthetic foam is selected from the group consisting of polyurethanes and polystyrenes.

14. A foundation construction according to claim **7** wherein said perforated conduit is a series of conduits independently spaced and distributed within the cushion of particulate material.

15. A foundation construction according to claim **14** wherein said series of conduits comprise at least one communicating pair of inlet and outlet conduits.

16. In a building structure for northern regions having a building supported on a foundation, the improvement wherein a pad is positioned beneath the building floor, said pad being substantially completely thermally isolated from the ambient environment and having at least one perforated and ventilated conduit placed within a cushion of air-permeable particulate material said cushion being encapsulated in synthetic insulating material.

17. The building structure according to claim **16** wherein said conduit comprises at least one communicating pair of inlet and outlet conduits.

18. A method of thermally insulating a frozen substrata from a structure located above said frozen substrata comprising installing beneath the structure a pad of air permeable particulate material having at least one perforated conduit positioned therein, encapsulating said pad with a thermal insulating material and intermittently forcing air through said conduit.

19. A method according to claim **18** wherein said thermal insulating material is a synthetic foam selected from group consisting of polyurethanes and polystyrenes.

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