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(54) **INTEGRATED ENERGY RECOVERY SYSTEMS**

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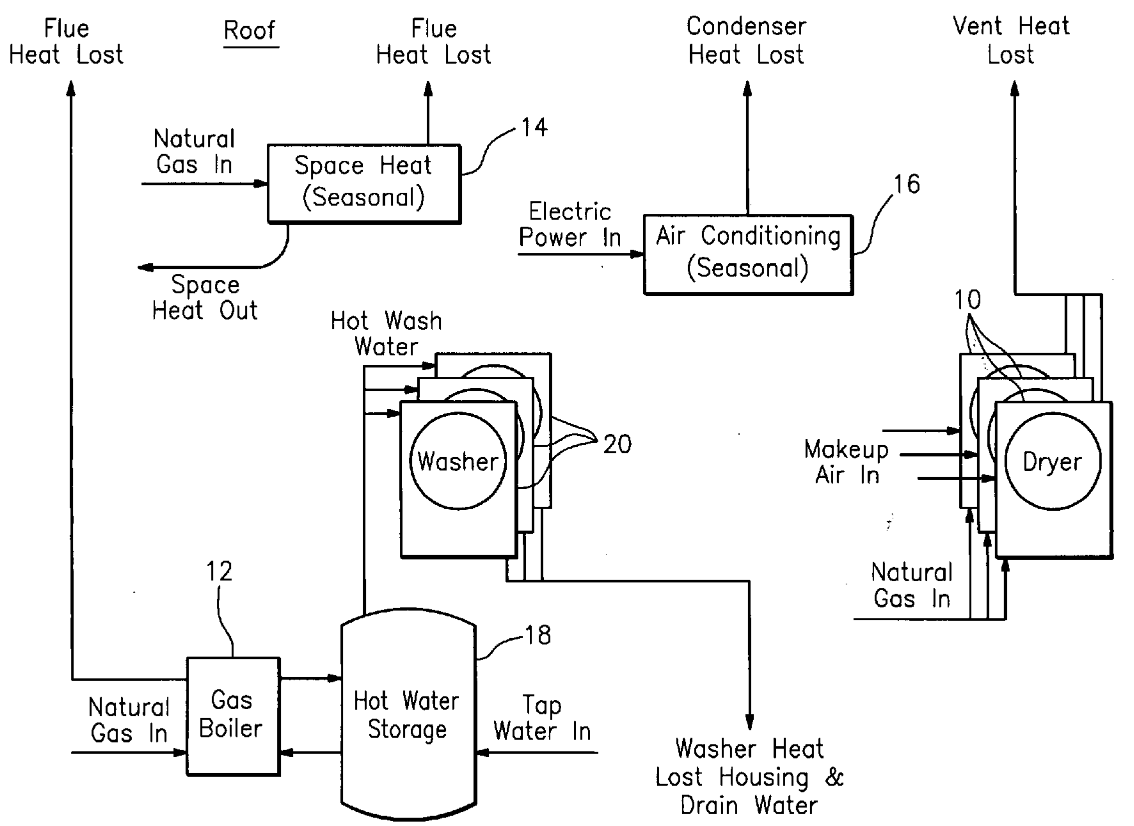
(57) **ABSTRACT**

An energy efficient laundry facility comprises a space heating system, an air conditioning system, a plurality of clothes washers, a plurality of clothes dryers, a hot water storage tank supplying the washers, a source of cold water and conduit means interconnecting the aforesaid. Dedicated heat recovery units are associated respectively with the dryers and employ high temperature dryer exhaust air to heat water for supply to the storage tank. A controller and temperature sensing means regulate the flow of hot water from the dryers to the storage tank. High temperature water is directed to the top of the storage tank and lower temperature water to an intermediate point in the storage tank. Hot water from the dryers is also directed to the space heating system. Each heat recovery unit comprises a heat exchanger, a blower, a water circulation pump, a water temperature sensor, and a dedicated controller. The controller may also include a dryer exhaust pressure monitor, a pressure controller, and a variable speed blower drive. The heat exchanger is of the counterflow type and each recovery unit has its heat exchanger and blower arranged to provide for right angle air flow resulting in a compact unit for mounting atop a clothes dryer. Hot water may also be drawn from the storage tank for use in either an air or hydronic space heating system.



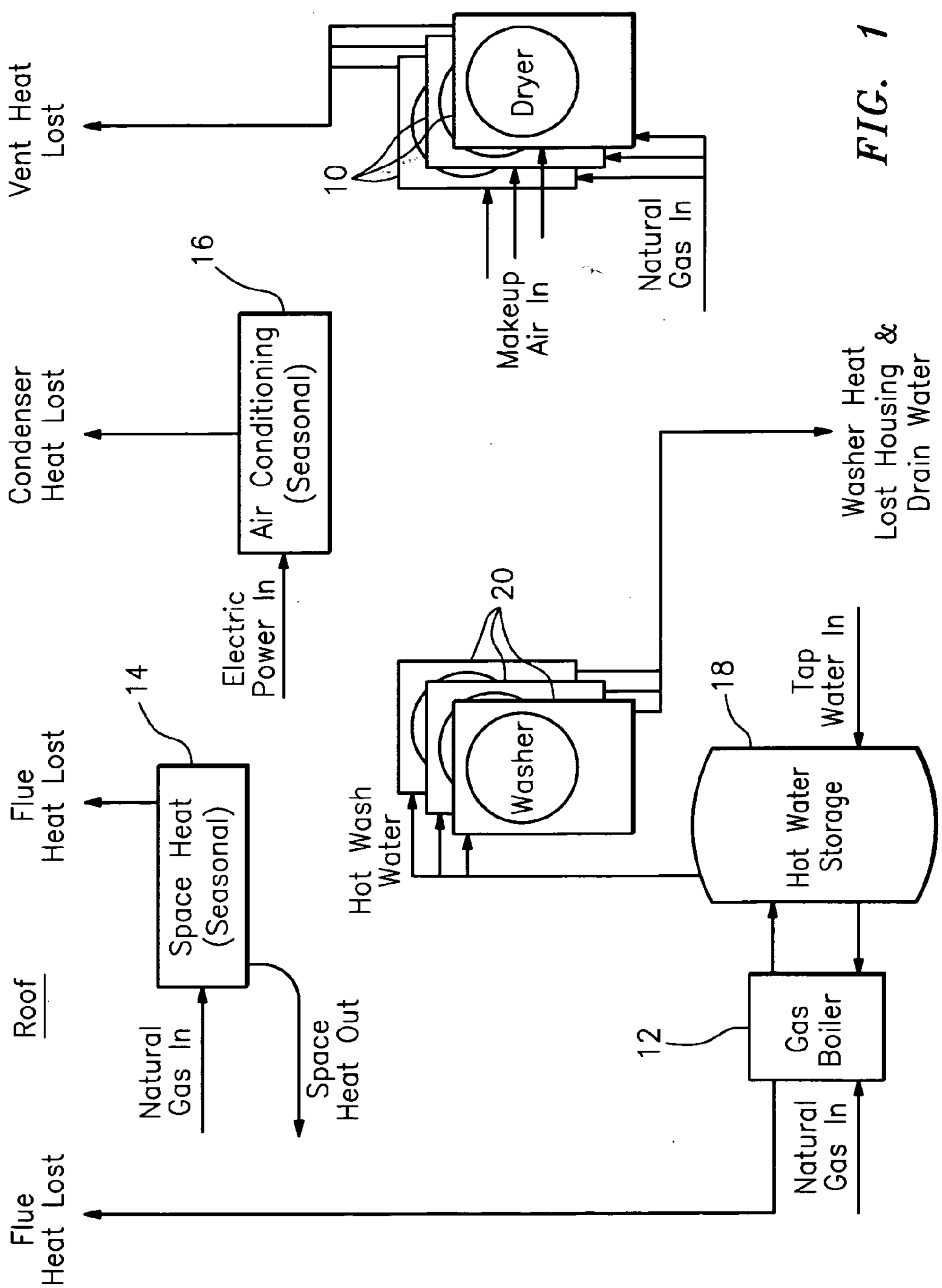

Roof
Flue Heat Lost
Natural Gas In
Space Heat (Seasonal)
14
Space Heat Out
Flue Heat Lost
Electric Power In
Air Conditioning (Seasonal)
16
Condenser Heat Lost
Vent Heat Lost
10
Dryer
Makeup Air In
Natural Gas In
20
Washer
Hot Wash Water
Washer Heat Lost Housing & Drain Water
18
Hot Water Storage
Tap Water In
12
Gas Boiler
Natural Gas In

FIG. 1

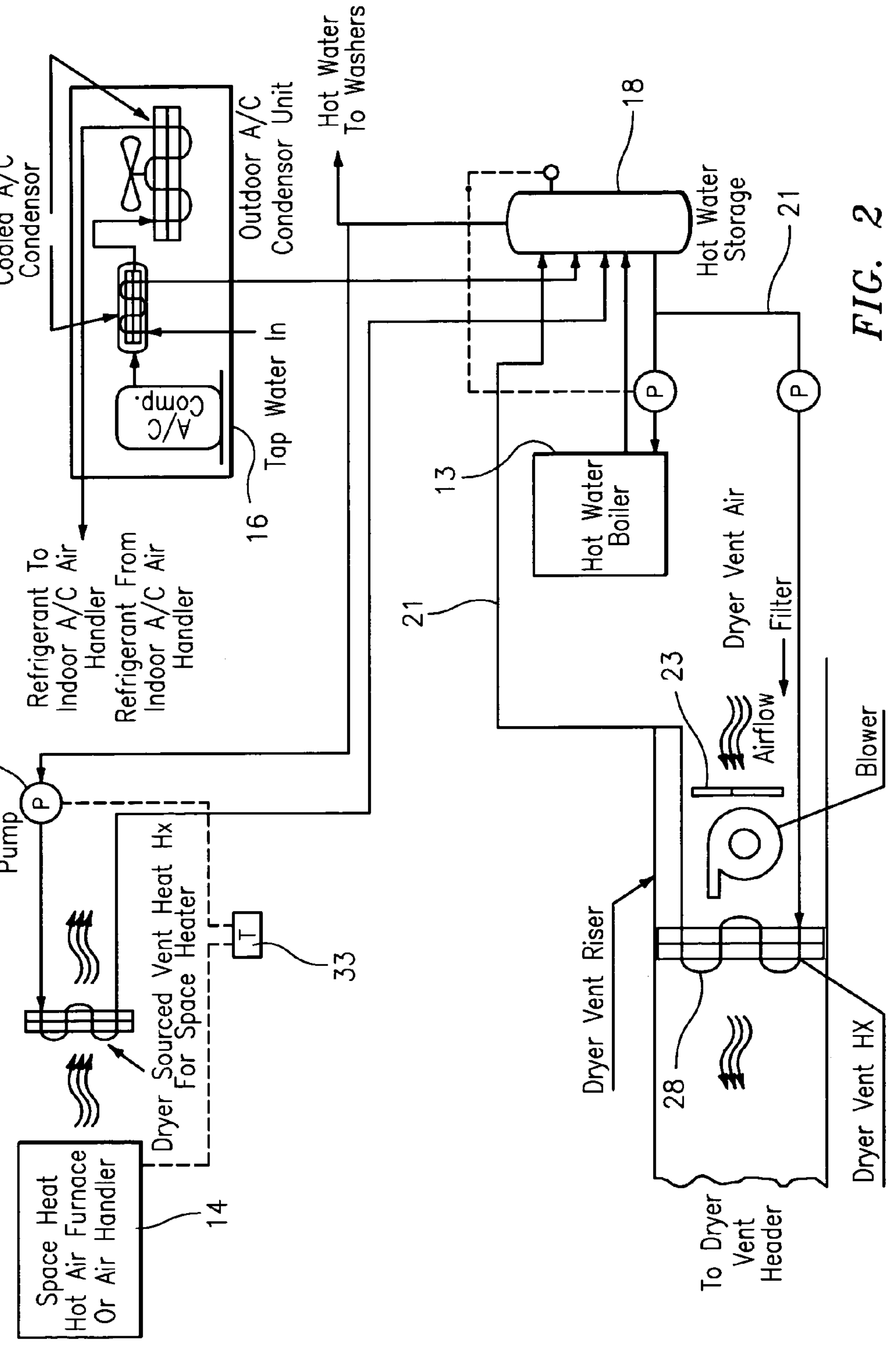

Retrofit Water Cooled A/C Condensor
Outdoor A/C Condensor Unit
A/C Comp.
Tap Water In
16
Refrigerant To Indoor A/C Air Handler
Refrigerant From Indoor A/C Air Handler
Hot Water To Washers
18
Hot Water Storage
21
P
13
Hot Water Boiler
Dryer Vent Air
Filter
21
23
Airflow
Blower
Circulator Pump
31
Dryer Sourced Vent Heat Hx For Space Heater
T
33
Space Heat Hot Air Furnace Or Air Handler
14
Dryer Vent Riser
28
Dryer Vent HX
To Dryer Vent Header

FIG. 2

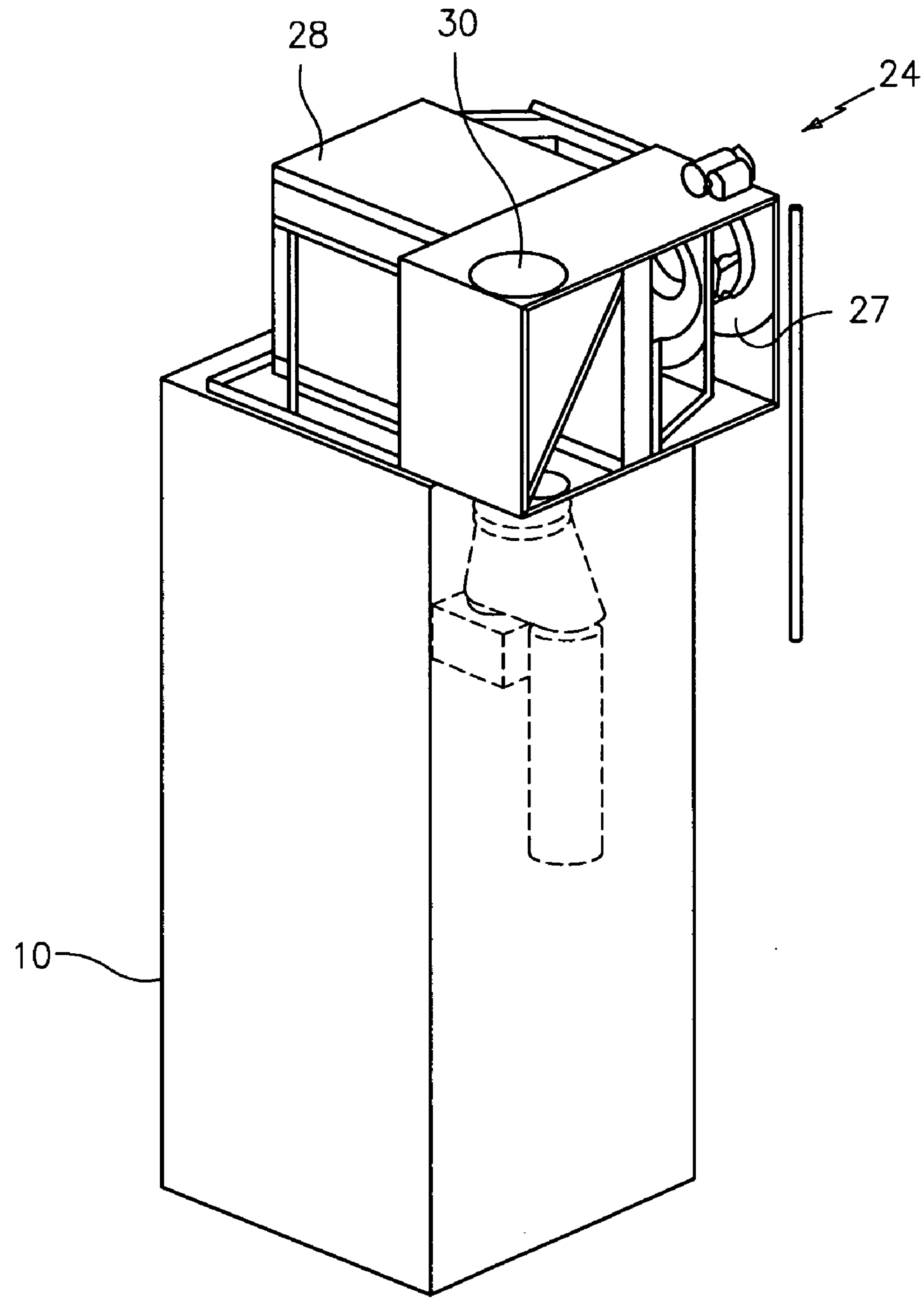


FIG. 3

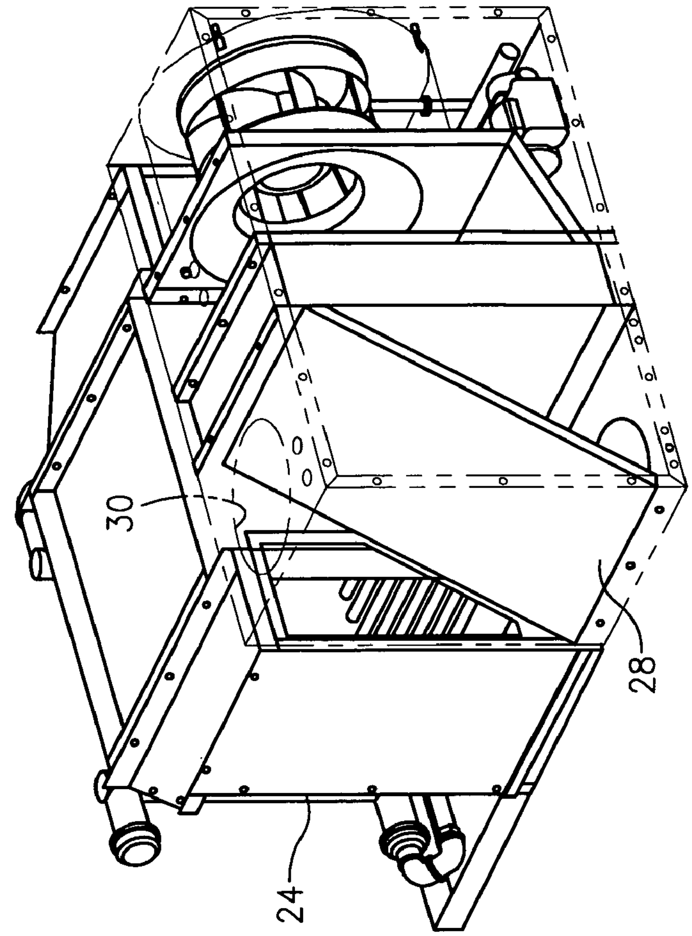


FIG. 5

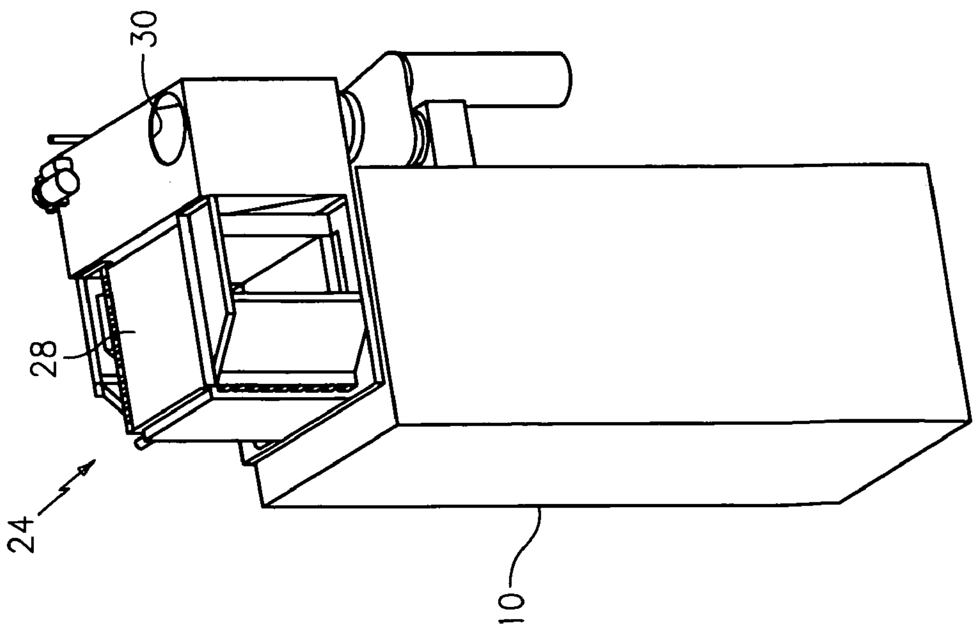


FIG. 4

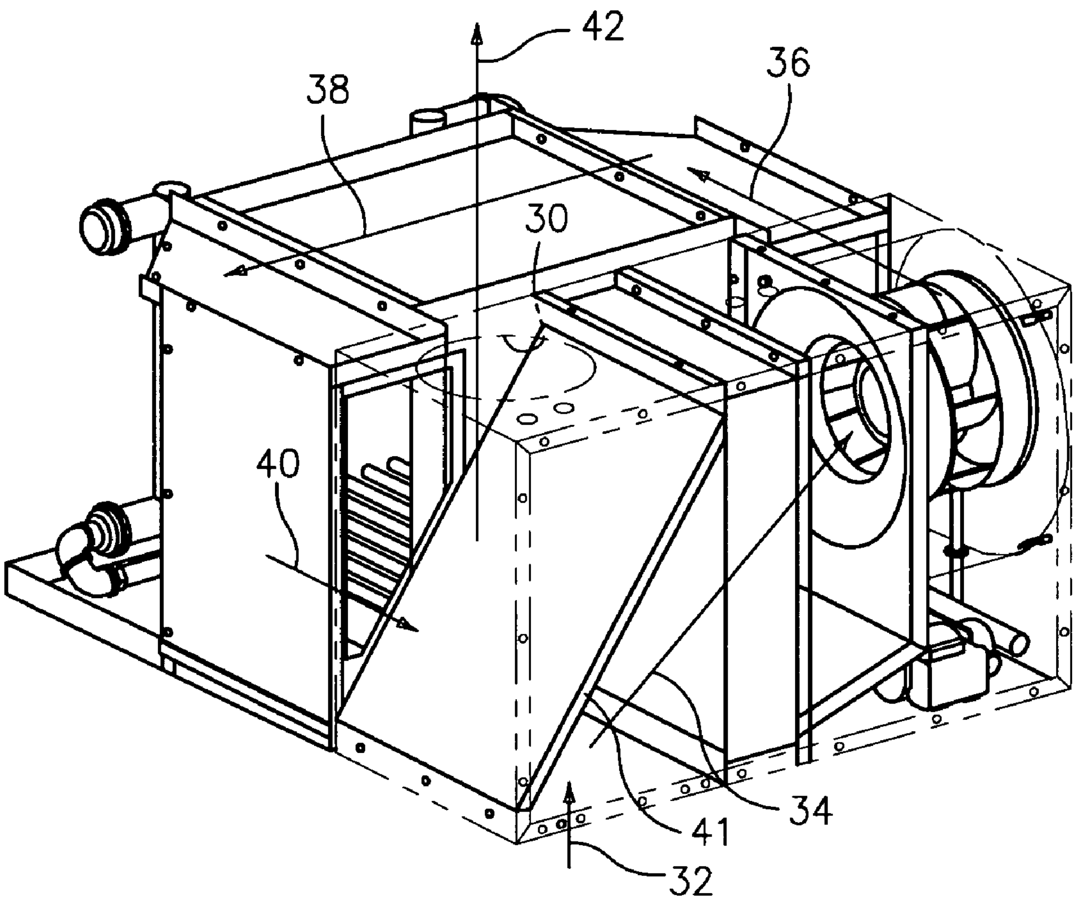


FIG. 6

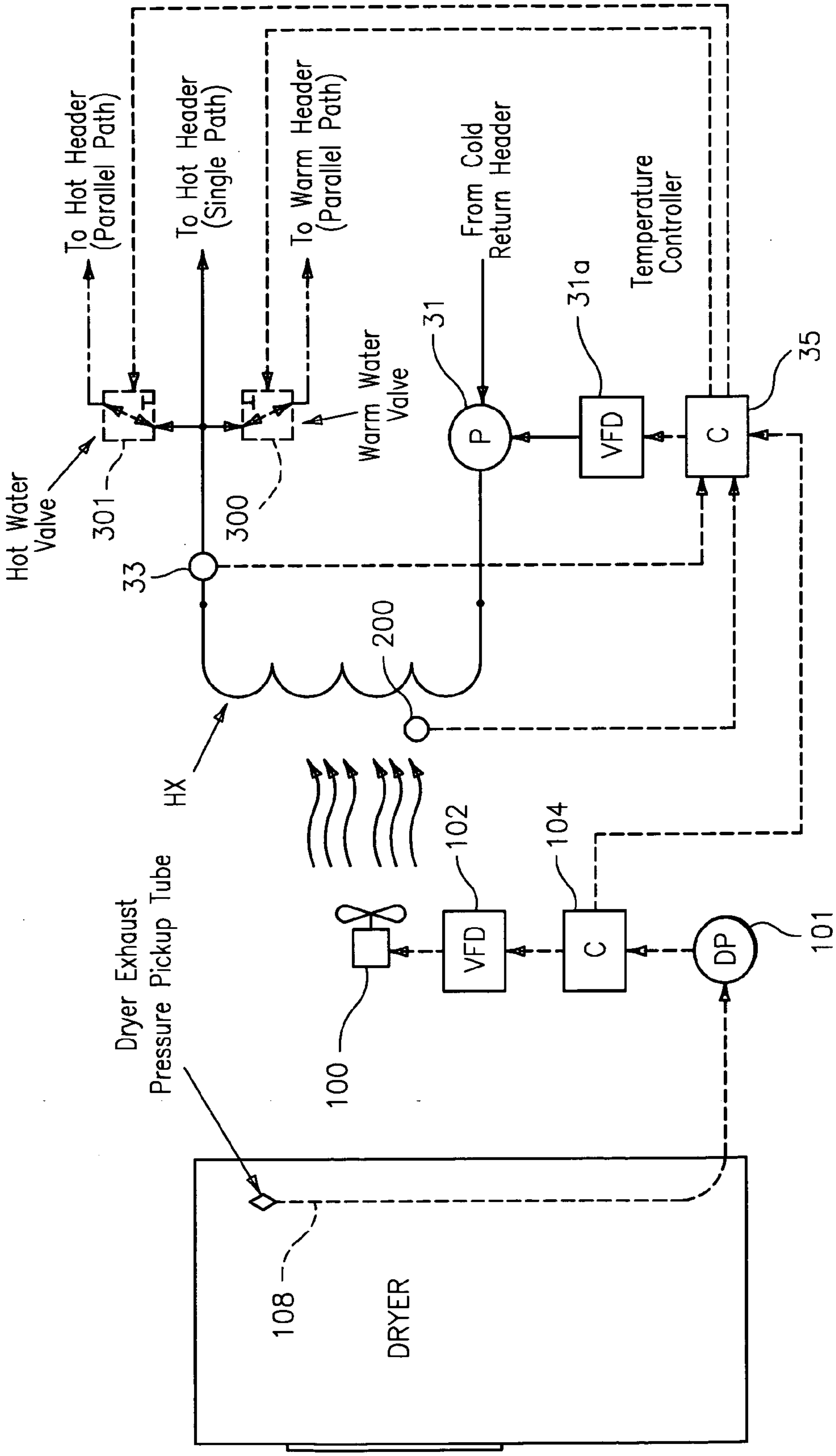

To Hot Header (Parallel Path)
To Hot Header (Single Path)
To Warm Header (Parallel Path)
From Cold Return Header
Temperature Controller
Hot Water Valve
Warm Water Valve
301
300
33
31
31a
35
P
VFD
C
200
HX
Dryer Exhaust Pressure Pickup Tube
102
104
VFD
C
DP
101
100
108
DRYER

FIG. 7

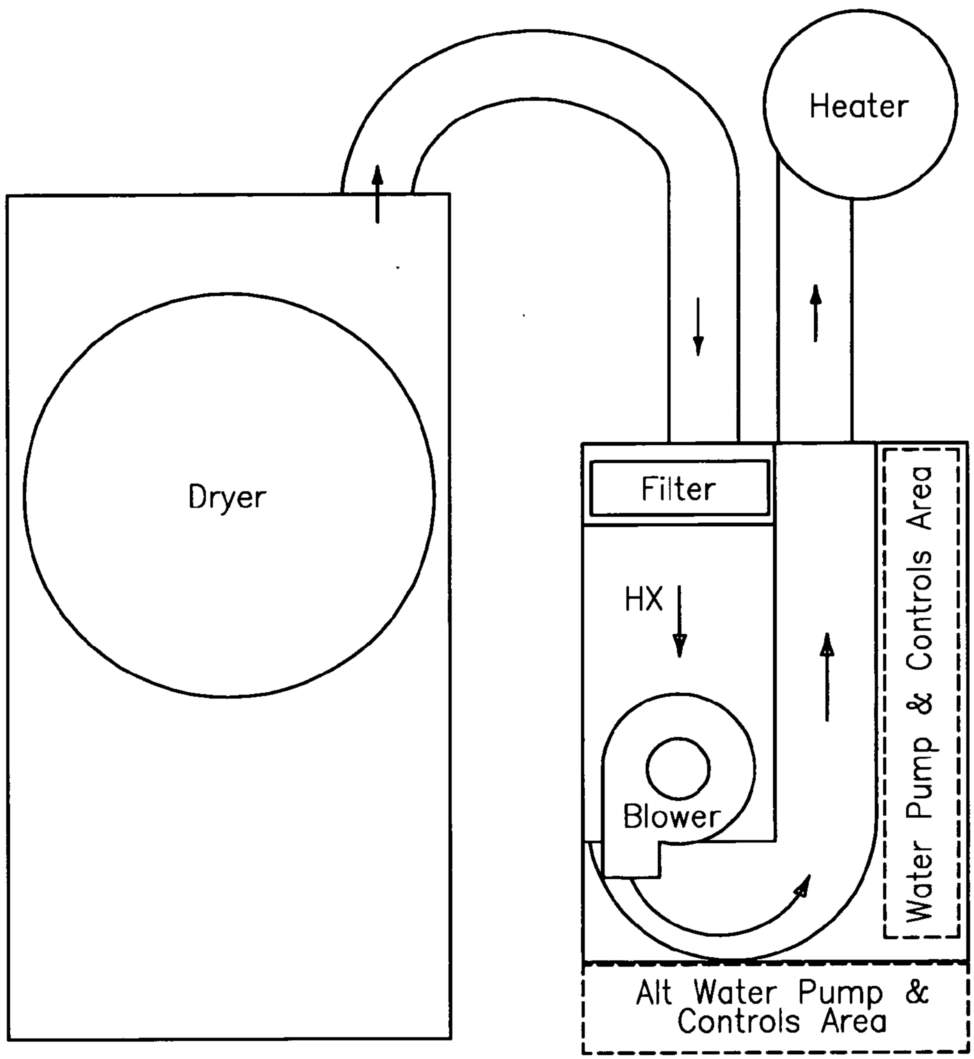

Heater
Dryer
Filter
HX
Blower
Water Pump & Controls Area
Alt Water Pump & Controls Area

FIG. 8

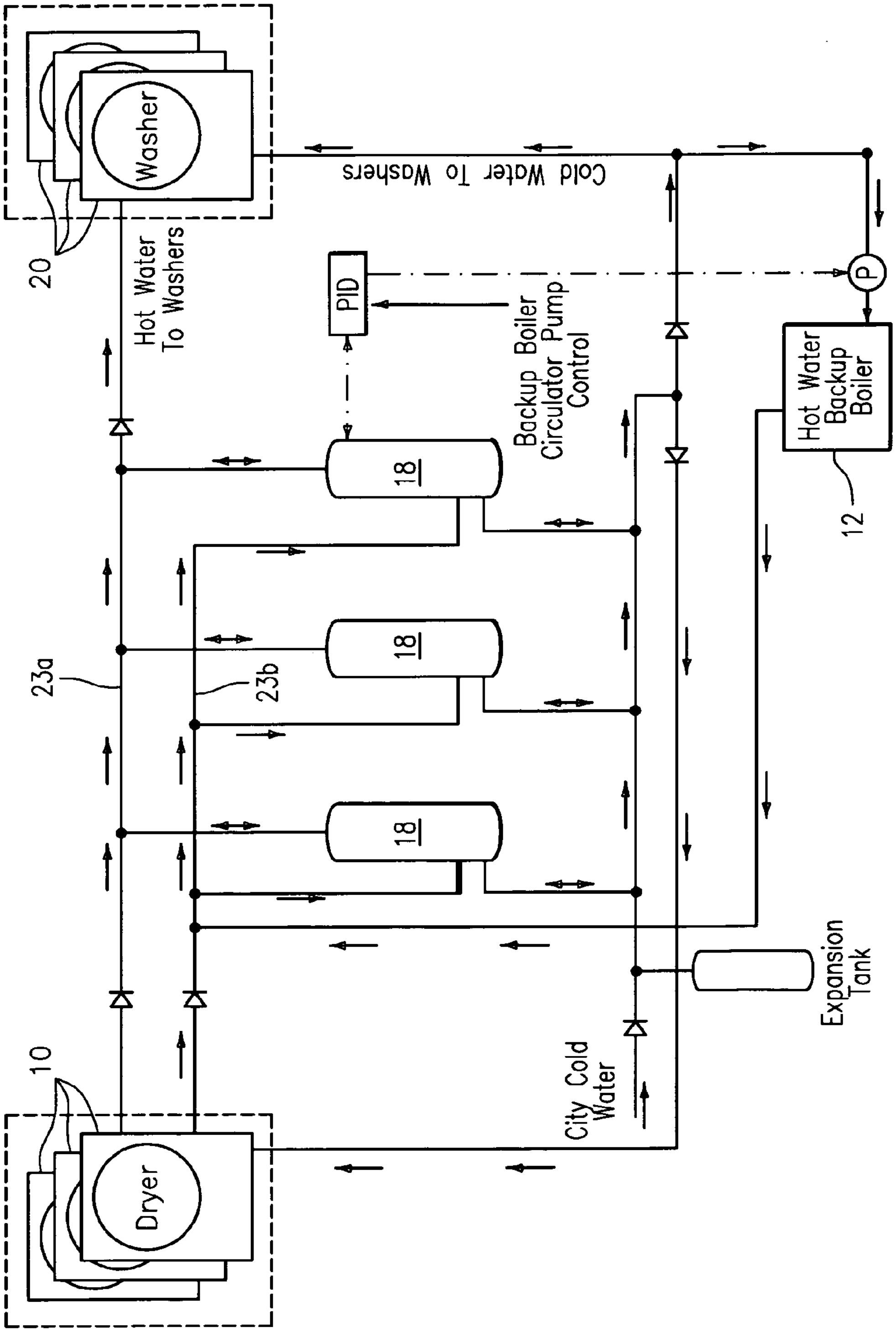

Washer
20
Cold Water To Washers
Hot Water To Washers
PID
Backup Boiler Circulator Pump Control
P
Hot Water Backup Boiler
12
18
18
18
23a
23b
Expansion Tank
City Cold Water
10
Dryer

FIG. 9

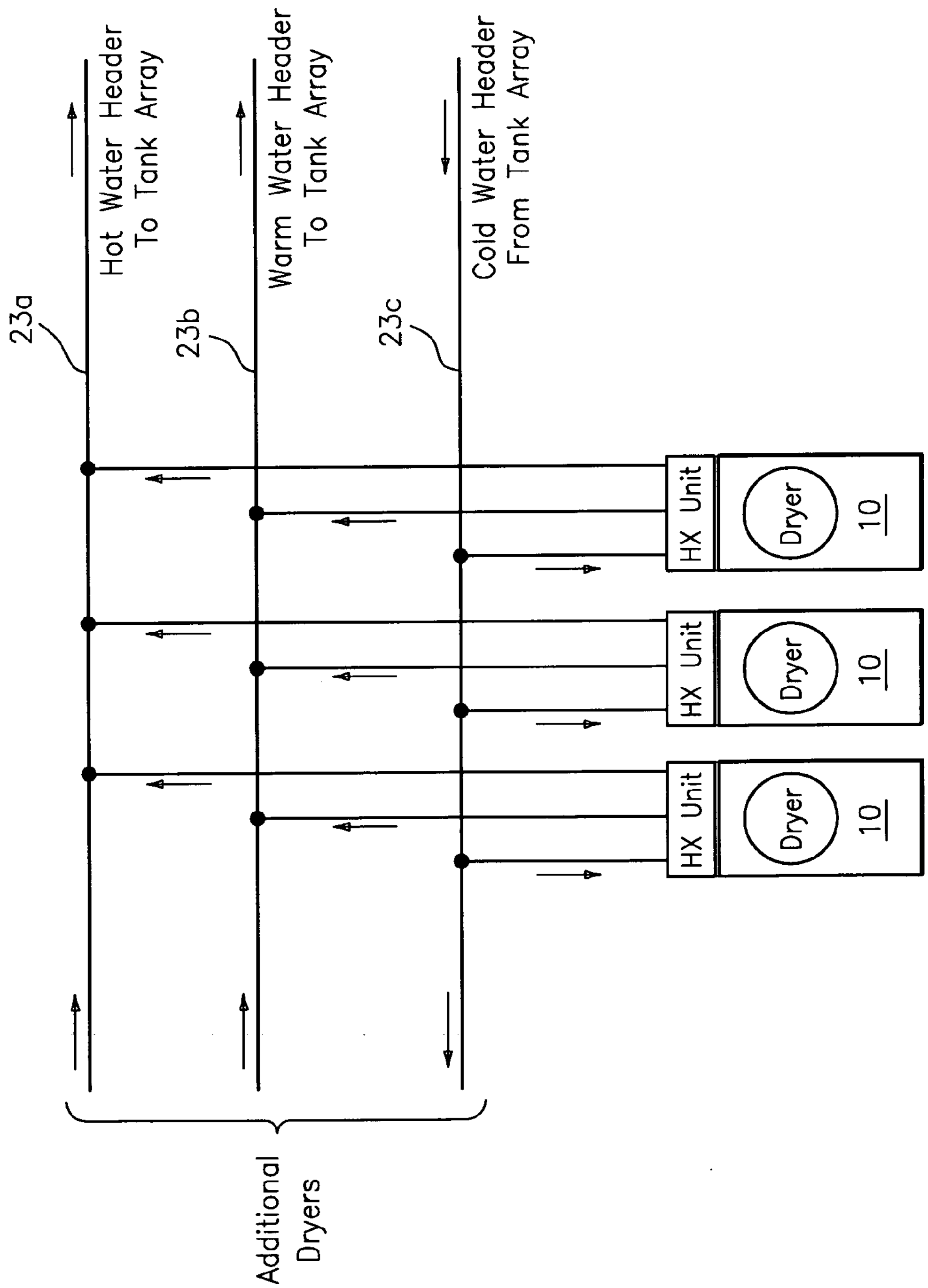

23a
Hot Water Header
To Tank Array
23b
Warm Water Header
To Tank Array
23c
Cold Water Header
From Tank Array
HX Unit
Dryer
10
HX Unit
Dryer
10
HX Unit
Dryer
10
Additional
Dryers

FIG. 10

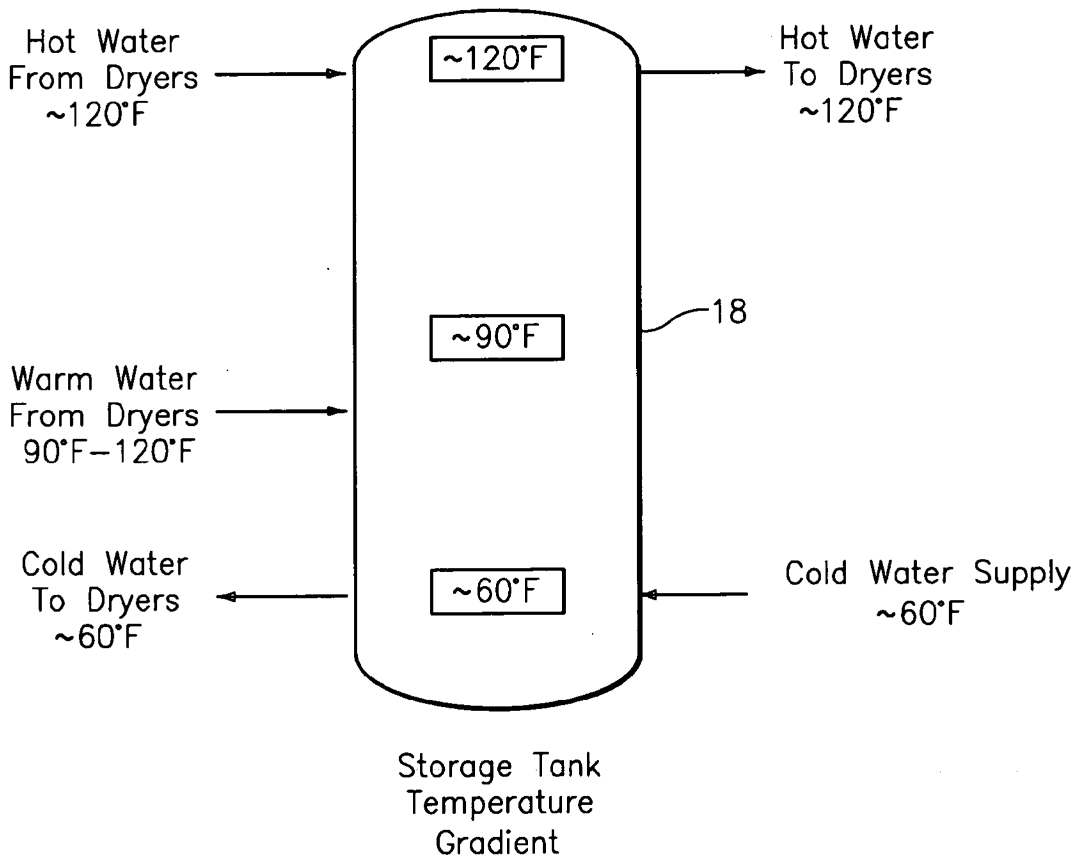

Hot Water
From Dryers
~120°F
~120°F
Hot Water
To Dryers
~120°F
18
~90°F
Warm Water
From Dryers
90°F–120°F
Cold Water
To Dryers
~60°F
~60°F
Cold Water Supply
~60°F
Storage Tank
Temperature
Gradient

FIG. 11

INTEGRATED ENERGY RECOVERY SYSTEMS

REFERENCE TO RELATED APPLICATION

[0001] Reference is had to Provisional Patent Application entitled Integrated Energy Recovery Systems, inventor Michael Goldberg, filed Jun. 18, 2009, hereby incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] Energy cost and availability are currently forefront issues well known to all. Research and investment are focused intensely on many facets of this dilemma, and much is being accomplished. In many industries, energy recovery is a key area of development. Typically, unused process heat that has historically been vented to the atmosphere or discharged into waterways, is now being captured. The captured heat may be used to preheat a target process and reduce energy consumption, or it may be used as the source heat for other processes in the same facility.

[0003] While heat recovery is an elegant way to reduce energy consumption, it can only work where the waste heat is discharged at sufficient temperature to be useful. It is also essential that the beneficiary process consume energy at least substantially equal to the available waste heat. For example, supermarkets commonly capture the heat from their chillers and central A/C systems and use it to preheat domestic hot water. However, their domestic hot water consumption is low, and only a small portion of the A/C waste heat is recovered. This is unfortunately often the case.

[0004] The laundry industry, however, is unique. The key processes that discharge and employ waste heat occur at temperatures that are compatible with each other, and laundries consume large quantities of water. This presents a unique opportunity to recover a relatively high level of waste heat, materially reduce carbon load, and provide significant financial benefits to the laundry owner. Laundries are extremely energy intensive, so much so that utility costs present an imminent threat to the industry's survival. Despite the urgency of its need, the laundry industry has largely fallen under the research radar, and little energy efficiency innovation has occurred to date. Mainstream laundry equipment manufacturers have recently begun to recognize the issue, and have engaged in extensive promotion of ostensibly energy efficient products. However, the improvements offered by these products are incremental and do not offer tangible relief to the industry. This profound stress on the laundry industry, and the nearly total solution vacuum, presents an urgent need for innovation.

[0005] The general object of the present invention is to provide an improved heat recovery system particularly adapted for use with clothes dryers and washers in commercial laundries but which may also have broad application in other environments.

SUMMARY OF THE INVENTION

[0006] In accordance with the present invention and in fulfillment of the foregoing object, the improved heat recovery system takes advantage of two key factors; compatible energy consumption and temperature in the separate processes, and very high water consumption. One function of the disclosed systems is recovery of waste heat from the dryer exhaust. This recovered heat is preferably used for hot water production, and may also be used for heating dryer makeup air and/or for facility space heat. In the event the facility Air Conditioning is water cooled, additional waste heat may be recovered, and Air Conditioning electrical consumption may be materially reduced.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. **1** is a schematic illustration in block diagram form of a conventional commercial Laundromat including a plurality of washers, a plurality of dryers, a boiler and hot water storage tank feeding the washers, a space heating system, and an air conditioning system,

[0008] FIG. **2** is a schematic illustration in block diagram form showing the-Laundromat of FIG. **1** equipped with an improved heat recovery system of the present invention,

[0009] FIG. **3** is a schematic illustration of a heat recovery unit mounted atop a commercial stacked dryer assembly comprising upper and lower dyer units,

[0010] FIG. **4** is schematic illustration of a heat recovery unit on a dryer assembly similar to FIG. **3** but from a different angle,

[0011] FIG. **5** is an enlarged fragmentary schematic illustration of a heat recovery unit constructed in accordance with the present invention,

[0012] FIG. **6** is an enlarged fragmentary schematic illustration of a heat recovery unit similar to FIG. **5** but with arrows indicating the direction of air flow through the unit,

[0013] FIG. **7** is a schematic diagram illustrating the controls for the heat recovery units,

[0014] FIG. **8** is a schematic diagram of a "straight through" configuration of the heat exchanger and blower in a recovery unit,

[0015] FIG. **9** is a schematic illustration of an overall system which might be installed in a laundry and is similar to FIGS. **1** and **2** but includes additional conduit means,

[0016] FIG. **10** is a fragmentary schematic view showing additional conduit means connecting a plurality of dryers to a number of different headers, and

[0017] FIG. **11** is a schematic illustration illustrating temperature gradients in a storage tank.

DESCRIPTION OF PREFERRED EMBODIMENTS

[0018] In a typical commercial laundry of the vended type as shown in FIG. **1**, the key energy consuming processes are the dryers **10**,**10**, washers **20**,**20** hot water boiler **12**, the facility space heating system **14**, and the facility air conditioning system **16**. Each of these processes consumes significant energy, and discharges waste heat to the atmosphere and/or down the drain. Laundries generally employ a boiler that consumes fuel, typically natural gas or oil, and heats water, which is then stored in a separate tank as at **18**. The washers **20**, **20** draw on the tank as needed, and when each cycle is completed, the water is discharged, still substantially hot, down the drain. The dryers **10**,**10** draw ambient air, and consume substantial energy to heat the air to very high temperatures, ranging from 325 F. for 30 lb. dryers, to 550 F. for larger machines. This energy is most commonly supplied as natural gas, although propane and oil fired dryers, as well as electric and steam heated dryers are also in use. Drying textiles is an adiabatic process, and except for heat loss directly through the housing walls, substantially all of the energy consumed is discharged out of the building via the dryer vent.

[0019] The building heating system **14** consumes energy as fuel, typically natural gas or oil, to heat the interior space. Furnace efficiency is typically about 80%, and approximately 20% of the heat is discharged to the atmosphere via the flue. Modern condensing furnaces are available with efficiencies as high as 97%, but these are uncommon in vended laundries. Furnace efficiency notwithstanding, energy consumed for space heat is substantial, and presents a significant corresponding cost burden to laundry facilities.

[0020] Air conditioning **16** consumes electrical energy to drive the refrigerant compressor and ancillary components. Air conditioning typically pumps heat from the air-conditioned space to an outdoor condenser coil, which is cooled by ambient outdoor air. All of the energy removed from the conditioned space, plus all of the energy consumed, is discharged to the atmosphere via the outdoor condenser.

[0021] A typical conventional hot water boiler and storage tank system operates as follows: An Aquastat controls the temperature of the water in the tank. The Boiler includes an internal fuel burner, which is automatically controlled by an internal thermostat (not shown). As washers draw hot water from the top of the storage tank **18**, cold makeup water is introduced at the bottom of the tank as from a city water supply. The influx of cold water gradually lowers the water temperature in the tank. When the Aquastat calls for heat, a circulator pump operates causing water to flow between the tank and the boiler. The boiler internal thermostat automatically cycles the burner on and off as needed to maintain a desired discharge water temperature. When the tank Aquastat is satisfied, the pump stops, and the burner subsequently shuts down.

[0022] Referring to FIG. **2**, storage tank **18** includes a separate recovery circulation loop **21** that communicates with a heat recovery unit **22** at each dryer. Most laundry venues have multiple dryers, in which case each dryer preferably has its own individual heat recovery unit **22**. In this embodiment, the heat recovery units are connected to common manifolds or headers **23** *a,b,c* (FIGS. **10**, **11**) which communicates with the recovery circulation loop. Dryers are typically installed in banks, with their exhaust ducts coupled in common to overhead manifolds or headers such as **23** *a,b,c*. In an alternative embodiment, a recovery unit **22** may be located at the common exhaust point of a bank of dryers. This embodiment, while potentially simpler, will typically deliver lower temperature water, as the air stream comprises exhaust air from a plurality of dryers at different points in their drying cycle, and thus at different temperatures.

[0023] As shown in FIGS. **3**, **4**, **5**, and **6**, in a system with a plurality of dryers and dedicated individual heat recovery units **22-22**, each heat recovery unit comprises a housing **24**, which is preferably mounted on top of its respective dryer **10**. The housing **24** encloses a blower **27** and an air to liquid heat exchanger **28**, preferably of the tube and fin type commonly found in conventional air conditioning equipment. Dryer exhaust air passes through the blower and heat exchanger, where substantial heat is transferred to the water circulating through the recovery loop. The dryer exhaust air, now at lower temperature, then exits the recovery unit at **30** and leaves the building via conventional ductwork.

[0024] In operation, heat collected from recovery units via the recovery circulation loop **20**, heats the water in the storage tank **18**. The heat collected from one dryer typically exceeds the heat required to supply hot water to a corresponding washer. In normal operation therefore, the aggregate heat recovered is at least sufficient or more than sufficient to maintain the temperature of the tank at the desired level, and the boiler circulator rarely or never operates. Correspondingly, the boiler burner rarely or never operates, and substantial fuel is not consumed.

Drying Thermodynamics

[0025] In normal operation, drying occurs in three stages, rising rate or warm-up phase, steady rate phase, and falling rate phase. During the warm-up phase, the dryer exhaust air temperature starts out relatively cool, near room ambient temperature, and slowly rises until it reaches the steady rate phase. During steady rate, the dryer exhaust temperature is relatively constant. In most vended commercial dryers this temperature is in the range of 160° F. to 180° F. at the highest heat setting. During this phase, the dryer exhaust heat content is at its maximum. Falling rate phase commences when the residual moisture remaining in the fabric is sufficiently low to limit capillary action that brings moisture to the surface, and the drying rate is correspondingly constrained. This causes the internal dryer controls to throttle or cycle the dryer burner (or other heat source) in order to maintain constant exhaust temperature. As a result, the heat output of the dryer is reduced.

Controls

[0026] It is desirable that the temperature of the water discharged from the recovery heat exchangers be relatively constant, and the same or higher than the desired wash water temperature. To ensure constant recovery water temperature over a wide range of dryer exhaust temperatures during the drying cycle, a novel closed loop temperature control algorithm is employed. A variable speed circulator comprising water pump **31** and variable speed drive **31***a*, a temperature sensor **33** that monitors discharge water temperature, and a closed loop control **35** delivers a proportional output to control pump speed FIG. **8**. The control is preferably a Proportional, Integral, Derivative (PID) type. When the recovery water temperature is below the target set point, the pump is effectively cut off and no water flows. As this temperature rises, and approaches the set point, the controller starts the pump at low speed, and varies the pump speed as needed to maintain constant water temperature. During warm-up, and falling rate phases, the pump speed is relatively slow. During the steady rate phase, when dryer heat output is at its highest, the pump speed is correspondingly at or near maximum.

[0027] In order to accurately monitor the temperature of the recovery discharge water, it is preferable that the temperature sensor be placed at a location immediately downstream of the heat exchanger discharge. While this presents the most accurate location for temperature measurement, it is only accurate when water is flowing. If there is no flow, this sensor simply measures the temperature of the standing water in the pipe, which over time will approach that of the ambient surroundings. The sensor is preferably insulated, but regardless will not provide accurate information unless there is some water flow. Water flow sufficient to provide accurate temperature sensing may be achieved by setting the temperature control device to provide a minimum pump speed signal that is slightly above zero, even when no flow is called for. The resulting water flow rate is preferably just enough to provide proper exposure to the temperature sensor, yet injects a negligible volume of low temperature water into the recovery loop. While this approach works well in principal, most commonly available circulation pumps, such as those used for hydronic heating systems, do not function well at very low speeds, and become very sensitive to output head pressure. When multiple dryers are connected to a common manifold, it is very difficult to reliably maintain very low flow rates.

[0028] In another embodiment, the temperature controller provides a true zero pump speed signal when no flow is called for, and instead generates a pulse train that jogs the pump at normal speed for a suitable brief period, at a suitable repetition rate. This ensures substantial flow and sensor exposure during the pulse dwell time, regardless of how many other pumps are operating, but in the aggregate, injects negligible low temperature water into the recovery loop. In practice, a pulse of approximately 1.5 seconds, at nominal 30 second intervals, has proven very effective. As the temperature of the water rises, the controller will call for increased pump speed, and the pulse train will become irrelevant. The control algorithm may be configured to stop the pulsing at this time, or it may simply continue. In practice it has negligible effect when the controller is calling for substantial water flow.

[0029] Dryers are extremely sensitive to vent back pressure, and will typically tolerate ductwork pressure drop of only 0.3" H2O. It is therefore desirable that the dryer heat recovery unit not introduce additional pressure drop to the vent ductwork. This may be accomplished by an integral fan or blower **100** and automatic pressure control, FIG. **7**, comprising dryer exhaust pressure sensor **101**, Proportional, Integral, Derivative (PID) closed loop control **104**, and variable spped drive **102**. The exhaust pressure sensor may be remotely located, and couples to the dryer exhaust via pickup tube **103**.

[0030] Still another embodiment comprises a very low pressure drop heat exchanger, with widely spaced fins or finless configuration.

[0031] Pump operation is desirably enabled only when the dryer is operating and the exhaust air temperature has reached a suitable set point. It is desirable to determine this state without the need for connecting to the internal dryer controls, or otherwise modifying the dryer. Thus, a signal is provided by the blower speed controller, such as a dry relay contact or the like, that indicates the blower is operating. This will reliably indicate when the dryer is operating, with no need to invade the dryer itself. Dryer exhaust air temperature may be determined by a temperature sensor **200** or thermostat at a suitable location within the recovery unit housing, upstream of the heat exchanger.

Latent Heat

[0032] When the dryer stops, substantial latent heat remains entrained in the heat exchanger. It is desirable to recover this heat rather than allow it to dissipate while the dryer is idle. To advantageously recover this latent heat, the control algorithm of the disclosed embodiment does not inhibit pump operation when the dryer shuts down. It instead continues to operate the pump, preferably under PID control, until the output water temperature falls below 120° F.

[0033] The ability to recover latent heat from the heat exchanger after the dryer stops is advantageous, but presents a potential runaway condition. Toward the end of a typical laundry business day, the tank will become saturated, and the temperature of the return water from the tank to the dryers will be higher than 120° F. If the pump remains under PID control while the dryer is idle, a plurality of pumps may continue running through the night until the tank return water falls below 120° F. This is detrimental causing excessive run time on the pumps, and depletes a portion of the stored energy in the tank.

[0034] Thus, provision may be made to prevent the pump from running continuously when the dryers are idle, even if the return water is at or above the set point. This may comprise a time delay function that allows the pump to operate during a dwell interval, sufficient to extract any latent heat remaining in the heat exchanger, and then turns the pump off, independently of the water temperature. The algorithm may thus comprise an AND logic function; and the pump will continue to operate when the dryer stops IF the water temperature is above 120° F. AND the dwell interval has NOT elapsed.

[0035] When the laundry is closed and the dryers are not operating, wind impinging on the outdoor vent discharge can occasionally trigger a dryer vent pressure sensor, and cause the blowers to run briefly. This in turn can cause a false dryer run state, and enable the pump. In this state, the pump will cycle at its nominal temperature sampling pulse rate. While occasional events are not serious, in moderately windy conditions, pump cycling can be sufficient to partially deplete the water tank stored heat.

[0036] In a preferred embodiment, the controller includes a dryer exhaust air temperature sensor **200** in the Heat Exchange unit intake area, and disables the pump if the dryer exhaust air is below a desired setpoint, such as 120 F.

[0037] In this embodiment, the time delay function discussed above is not required. The algorithm may thus comprise an AND logic function; and the pump will continue to operate when the dryer stops IF the water temperature is above 120 F AND the dryer exhaust air is above the desired setpoint.

Storage Tank Configuration

[0038] The hot water storage tank **18** is described herein as a single tank. This tank may, however, advantageously comprise a plurality of tanks piped together in parallel and acting as a single tank. This embodiment offers easier installation and flexibility of placement in venues with limited space or access.

Low Grade Waste Heat Recovery

[0039] While recovery of waste heat at high or even moderate temperatures is well known and relatively straightforward, recovery of very low grade heat requires careful design. In the laundry under consideration the source hot air temperature is close to the target water temperature, providing a small delta T to drive the requisite heat transfer. The process heat exchangers must operate effectively with low delta T (approach), and very low heat loss must be maintained throughout the process.

Heat Exchanger Circuiting

[0040] In order to achieve very low approach temperature across the Heat Exchanger (The temperature difference between the hot source air and the beneficiary water.) it is desirable and advantageous for the refrigerant (water) flow path to be as close as practical to a continuous path in the opposite direction of the air flow, referred to in the industry as counterflow. Counterflow design places the hot air entering the Heat Exchanger adjacent to the heated water exiting the Heat Exchanger at the same end, providing the hottest possible water. At the other end of the Heat Exchanger, the air is cooler, having given up considerable heat, but is adjacent to the entering water, which is also at its lowest temperature, having yet to extract any heat. This embodiment ensures that the highest practical temperature difference between the water and the air is maintained across the entire flow path of the Heat Exchanger, maximizing the heat transferred.

[0041] Typical tube and fin coils found in conventional Heat Exchanger are necessarily serpentine, to facilitate practical manufacturing and form factor. The tubing is circuited to optimize drain back of condensed refrigerant in the case of a condenser, and refrigerant vapor rise in the case of an evaporator. As a result, the refrigerant flow is not in a continuous path counter to the air flow; rather the refrigerant tubing reverses course numerous times throughout the coil, traversing repeatedly from counterflow to concurrent flow. This is acceptable in a constant temperature process such as condensing or evaporating of refrigerant, but for processes in which neither fluid changes state, and both fluids exhibit a temperature gradient over their flow path, as in the present embodiment, this circuiting is prohibitively ineffective for low delta T applications. The present embodiment employs novel circuiting in which the water flow is at all times either normal to or counter to the air flow. This novel circuiting takes advantage of the fact that the water does not change state, and consequently drainage is not a material concern. Rather than traversing from counterflow to concurrent flow, the tubing traverses vertically, from upflow to downflow. This vertical switchback does not materially affect fluid flow or Heat Exchanger performance, and maintains near ideal counterflow progression of the water with respect to the airflow. The arrangement discussed is illustrative only, and other counterflow circuiting may be employed.

Wraparound Airflow, Compact Form Factor

[0042] The substantial heat available in the dryer exhaust air necessities a relatively large heat exchanger. This, combined with the blower and a lint filter, comprise a long airflow path, with inconvenient dimensions and substantial housing surface area. As illustrated in FIG. **6**, the present embodiment employs a novel wraparound airflow path as indicated by arrows **32**-**42**. This advantageously accommodates a symmetrical compact housing that is smaller than the footprint of the host dryer and minimizes housing surface area, thus minimizing heat loss through the housing walls.

Dedicated HX Unit Per Dryer

[0043] A simple arrangement comprises a common recovery unit installed in communication with the common exhaust air discharges of a bank of multiple dryers. While simple in principal, this embodiment suffers from airstream temperature dilution. At any given time in the course of a day, a plurality of dryers will be operating at various points in their cycle. The exhaust air from those that are in their warm-up or falling rate phase will be at lower temperature than those in steady rate phase, and the aggregate air temperature will be the mean of all sources. This temperature will often be lower than that needed to deliver water at the desired temperature. In addition, if a common heat exchanger fails, all heat recovery from that bank will be lost, and depending on the failure mode, the connected dryers may be forced out of service.

[0044] Laundries do not adhere to a common design, and are found in a wide variety of sizes, layouts, and equipment compliments. Servicing the vast variety of venues, with a common recovery unit embodiment, will require a large inventory of different size units, and will often require customization. The present invention envisions individual independent recovery units installed respectively on top of each host dryer. This advantageously permits independent operation of each unit, with no dilution of the hot water output. In addition, if one recovery unit fails, other dryers are unaffected. This arrangement, comprising an independent recovery unit at each dryer, will serve laundries of any size and configuration with a minimum number of recovery unit models. Most laundries can be served with a single model, advantageously simplifying manufacturing, reducing inventory requirements, and presenting easier installation.

Recovery Units On Top of Dryers

[0045] The compact form factor of the present embodiment takes advantage of headroom above the dryer, which is common in vended laundries, and is often the only available space. Each recovery unit is preferably installed directly on top of its host dryer. No floor space is required for the recovery units, a significant advantage as floor space is precious in this industry, and no remodeling of facility or rearranging of equipment layout is needed.

Direct Connection

[0046] Dual drum stack type dryers with upper and lower units, typically have a single exhaust vent connection directly on the top of the housing. Thus, the recovery unit dryer air input connection, for use with this type of dryer, is advantageously located on the underside of its housing, corresponding with the location of the dryer vent connection. The two connections then mate when the recovery unit is placed on the dryer. This connection may be provided with a sealant or with a suitable resilient gasket, donut, or any other suitable sealing means. This advantageously eliminates the need for ductwork between the dryer and the recovery unit.

[0047] To facilitate alignment between the dryer vent connection and the recovery unit air intake connection, the intake connection may comprise an oversize opening. This opening includes a cover plate larger than the oversize opening, in which a correctly sized opening is located. The cover plate may then be translatable over a suitable range, allowing the installer to precisely align the intake opening with the dryer exhaust connection. Once in position, the cover plate may be locked in place with screws, clips, or any suitable fastening means. This advantageously accommodates installation of the unit on dryers of different makes and models.

Indirect Connection

[0048] For dryers with a vent connection on their rear panel relatively close to the floor, as is common with single drum dryers, a short length of suitable ductwork may be employed. To facilitate this, the recovery unit air intake, for use with single pocket dryers, is located on the back side of the housing, preferably on the same side of the dryer as the vent connection.

Universal Connectivity

[0049] To facilitate convenient manufacturing, installation, and minimal inventory requirements, the recovery unit may be installed interchangeably on both rear and top vented dryers. Thus, two oversize intake openings and two interchangeable cover plates may be provided, wherein one cover plate has a correctly sized opening as discussed above, and the other has no opening. The unit may then be configured for top venting or back venting dryers merely by attaching the cover plates to the desired opening.

Modular Two Piece Embodiment/Field Installable Design

[0050] The present embodiment is not especially ungainly, but is sufficiently large and heavy to encumber installation on top of dryers in confined work areas. To facilitate convenient manageable installation, the recovery unit may comprise two mating sections: the heat exchanger section, and the Air Handling section. Each section will be small and light enough for two technicians to handle without difficulty. The Heat Exchanger section would comprise the heat exchanger itself, a drain pan and plenum means to turn the air stream ninety (90) degrees, at the entrance and exit ends of the heat exchanger respectively. The entrance air and exit air openings would be in the same plane, for mating with the Air Handling section.

[0051] The Air Handling section would comprise a housing with a diverter damper, support and locating means for an air filter, and a blower. The air intake would preferably be located as discussed above. The water pump and the electrical/controls housing would be advantageously mounted on or in the Air Handling so as to be easily accessible from behind the dryer.

[0052] The Heat Exchanger section would be installed on top of the dryer first, and aligned into position. A suitable sealing material such as closed cell foam or the like would be attached to the Heat Exchanger or Air Handling section to provide an airtight connection between them. The air handling would be installed next, and placed in position snugly against the Heat Exchanger section. Suitable fastening means, such as screws or clips would be used to attach the two sections two each other. The completed air unit would then optionally be attached to the dryer. However, in practice this has proven unnecessary, and to avoid invading or modifying the dryer the unit may not be fastened to the dryer. Suitable elastomer strips, sheeting, or feet to absorb vibration and prevent sliding, may be attached to the recovery unit or placed on top of the dryer prior to installation, if desired. This facilitates convenient and straightforward transport and installation of the recovery units.

Passive Separator Damper (Diverter)

[0053] With reference to FIGS. **5** and **6**, dryer vent air enters at the bottom of the recovery unit and is directed to the blower and Heat Exchanger coil by diverter damper **41**. After passing through the blower and Heat Exchanger coil , the air is directed to the recovery unit exit port **30** by the opposite side of the same damper.

[0054] As shown in FIGS. **5** and **6**, the damper **41** is normally placed diagonally in the air handling entrance chamber, dividing it into two triangular sections. The damper may be hinged at the top, or may be removable. In the event of a system or blower failure, the user or service technician may relocate the damper to a vertical position in front of the filter. This may be accomplished by simply removing an access cover and rotating the damper around its hinge line to a vertical position, or removing the damper and replacing it in the vertical location. Clips, slots, edge guides, or other fastening means may be used to retain the damper.

[0055] When the damper is located in its vertical position, the dryer vent air flows unencumbered through the Air Handling directly to the air handling exit port, and the path through the filter to the blower and Heat Exchanger coil is blocked by the damper. Thus, in the event of a blower or other system failure, the recovery unit can be effectively bypassed in a very few minutes, with no special knowledge, permitting normal operation of the dryer pending repairs to the recovery unit.

[0056] In a more advanced embodiment, this feature may be linked to an external actuator, such as a knob or lever, such that the operator can simply set the damper to the ‘normal’ or ‘bypass’ position without removing access panels.

Alternate Form Factor

[0057] An alternative embodiment comprises a configuration shown in FIG. **12**. In this embodiment, the airflow path is straight, and the blower is the last item inline. A centrifugal blower at this location serves to turn the air 90 degrees, facilitating simple connection of the Heat Exchanger unit discharge to an overhead exhaust header. This Heat Exchanger places a relatively high suction load on the blower, which must be carefully chosen. It advantageously presents a relatively small footprint, reduced weight, and reduced manufacturing cost.

[0058] Self Drying Condensate Pan All embodiments of the Heat Exchanger unit include a condensate pan or catch tray to collect condensate from the Heat Exchanger. This condensate pan may include a drain connection that may communicate with a common drain manifold. Said manifold may communicate with a convenient drain, or may be connected to a conventional condensate pump such as used for central air conditioning installations. In a preferred embodiment, the condensate pan is metallic , and comprises the floor of the Heat Exchanger unit housing. When the unit is installed on top of the dryer, sufficient heat escapes through the top of the dryer housing to evaporate any water collected in the condensate pan. This advantageously eliminates the need for drain connections or condensate drainage handling.

[0059] Flat Pack Wall Mount

[0060] Another embodiment comprises a relatively thin flat Heat Exchanger unit housing that conveniently mounts on the wall behind each dryer. Intake and discharge are both at the top of the housing. A simple overhead inverted U bend of ductwork connects the dryer discharge to the Heat Exchanger unit intake.

[0061] In venues where the service hallway behind the dryers is sufficiently wide, this embodiment eliminates the need to hoist the Heat Exchanger unit onto the top of the dryer, and presents grade level access for cleaning and servicing. A further advantage is that in the event of a water leak, water cannot drain into the dryer.

[0062] Transparent Operation/Zero Installation Invasion

[0063] The recovery unit is entirely transparent to the dryer, ensuring uncompromised dryer operation and life, as well as compatibility with manufacturers’ warrantees. As described above in the fan control section, the recovery unit introduces zero backpressure to the dryer exhaust. Thus, the dryer is effectively ‘unaware’ of the unit’s presence. Dryer operational state, including whether one or both drums are operating, is preferably accomplished via vent pressure and/or airflow measurement, and/or exhaust air temperature measurement, requiring no connection to the internal dryer controls, or any other invasion or modification to the dryer.

Additional Features and Improvements

Parallel Path Low Temperature Water Injection

[0064] The recovery units preferably deliver output water at temperature equal to or slightly higher than the target water temperature. The water is therefore injected into the tank at the top, preferably at the same connection point to the hot wash water supply. This permits the washers to draw the hottest available water.

[0065] A substantial amount of additional heat is released during Warm-up or Rising Rate phase, when the dryer exhaust air is at temperatures below the target water temperature. This heat can be advantageously recovered, substantially increasing the total heat recovered in an embodiment which comprises an additional recovery discharge output, and a secondary or warm air manifold **23***b*. These additional outputs communicate via the secondary manifold with a water tank port, at a suitable location near the middle of the tank. This embodiment takes advantage of the natural temperature gradient in the tank, contributing heated water that is cooler than the target wash water, but warmer than the water at the injection point on the tank. This will contribute substantial additional heat to the system without compromising the target hot water temperature.

[0066] The controls for this embodiment preferably include an additional temperature setpoint, preferably between 90 F. and 120 F. When the water temperature at the Heat Exchanger discharge exceeds 90 F., the circulator pump operates, and a solenoid valve **300** or equivalent device opens directing Heat Exchanger discharge water to the secondary manifold **23***b* and subsequently to the center water tank port. When the water reaches 120 F., the first solenoid valve **300** closes, and a second valve **301** opens, directing Heat Exchanger discharge water to the primary, or hot, manifold **23***a*, and subsequently to the top water tank port.

[0067] An alternative embodiment may include a two position diverter valve (referred to in the industry as a three way valve), in lieu of two simple on/off solenoid valves (referred to in the industry at two way valves), which selects either the primary or secondary manifold.

Freeze Protection

[0068] Laundries are typically configured with banks of dryers set a few feet from an outside wall, and isolated from the public area with a valence wall, forming an isolated corridor behind the dryer bank. The outside wall is typically penetrated with makeup air openings comprising approximately 1 square foot per 30 pounds of dryer capacity. In typical vended laundries, the makeup air intakes can be over 20 square feet in area. In cold weather, cold makeup air is drawn in to the corridor behind the dryers. As the recovery units and their associated piping are water filled, the potential for freezing, particularly when the laundry is closed, must be addressed. In one embodiment, the system may he configured to drain back when the facility is closed, leaving the piping that is exposed to cold air empty. In another environment, the circulator pumps operate for a suitable short period, such as a few seconds to a minute, at a suitable interval, such as hourly. This may be controlled by a simple timer, or by a thermostat that activates each circulator when its respective heat exchanger temperature falls below a target set point, such as 35° F.

[0069] An alternative embodiment comprises active damper(s) at the makeup air intake(s), which close when the dryers are not in use, thus mitigating or eliminating the freezing risk. Although less than ideal from an energy use point of view, modest space heat may be also employed in the corridor to supplement freeze protection as needed.

Facility Space Heat

[0070] Hot water in the storage tank, in excess of that needed to supply hot water to the washers, may be used to supplement or supply space heat. Thus, water from the storage tank may be circulated on demand through a third loop that communicates between the tank and a heat exchanger in the space heating system. This heat exchanger is preferably a water to air type tube and fin construction. It is preferably located in the return air to the furnace, thus preheating the return air entering the furnace. When incoming air to the furnace is already at the desired temperature, the furnace will automatically modulate or shut down its internal burner, thus eliminating the fuel consumption requisite to space heat.

[0071] In another embodiment, in which the existing space heat is hydronic, hot water from the tank may be circulated directly through existing or additional baseboard or unit heaters, or may be coupled to the existing hydronic space heat system, via a water-to-water heat exchanger of any suitable type.

[0072] In still another embodiment that does not employ hot water from the storage tank, additional dryer vent heat may be extracted by a separate heat exchanger downstream of the recovery units in the dryer vent ductwork. This heat exchanger is preferably of the air to liquid type, such as a fin & tube configuration, with a separate dedicated circulation loop communicating with a similar heat exchanger in the furnace return air ductwork. Alternatively, the heat exchanger may be an air-to-air type, a heat pipe, or any other suitable configuration. It may be located in the recovery unit housing or in the dryer vent header ductwork.

Hybrid Water Cooled Air Conditioning

[0073] The preexisting water consumption typical of laundry facilities may be advantageously employed to water cool the facility air conditioning, without compromising laundry equipment performance, and with no incremental water consumption. The cold water supply line may pass through a heat exchanger in the Air Conditioning unit, thus water cooling the Air Conditioning and prewarming the supply water. Air Conditioning electrical consumption is thus substantially reduced. The heat exchanger may be an OEM device installed in the Air Conditioning unit during manufacture, or may be retrofitted to existing Air Conditioning equipment. The Air Conditioning heat exchanger may be of any suitable type, such as a coaxial coil, shell and tube, or flat plate. Cold tap water may pass through this heat exchanger and then to a hot water storage tank, and/or directly to a point of use, such as the washer cold water feed. This embodiment will require freeze protection in some venues. Freeze protection may be implemented as a self draining embodiment, which leaves the water side of the A/C heat exchanger dry when not in use.

[0074] In another embodiment, the Air Conditioning heat exchanger comprises a closed loop including a secondary heat exchanger at or near the cold water supply line, and a circulator pump. This closed loop may be filled with propylene glycol or other suitable antifreeze solution. Tap water then flows through the secondary heat exchanger, picking up heat from the closed loop, and indirectly cooling the Air Conditioning.

[0075] In still another embodiment, the Air Conditioning heat exchanger may be located inside the facility, and the Air Conditioning refrigerant piping routed into the building for connection to said heat exchanger. This embodiment is intrinsically freeze protected.

[0076] While it is known in the art to use Air Conditioning waste heat for preheating domestic hot water, the beneficiary process, e.g. the hot water, consumes a relatively small portion of the Air Conditioning heat output, and does not materially affect the efficiency of the Air Conditioning. While the present embodiment benefits from recovered Air Conditioning waste heat, the quantity is small in comparison to the recovered dryer heat. The principal object of the embodiment is water cooling of the Air Conditioning to substantially reduce Air Conditioning electrical consumption.

[0077] Water cooled Air Conditioning is known in the art, as is evidenced by tower cooled and ground coupled (geothermal) systems. However cooling Air Conditioning with a continuous stream of city water is not commercially viable, the water consumption is prohibitive. The disclosed embodiment advantageously takes advantage of the laundrys' preexisting water use.

[0078] A key feature of the present embodiment is a hybrid configuration comprising a refrigerant to water heat exchanger in series with an air-cooled condenser coil. This allows complete and transparent operational flexibility; the Air Conditioning will operate normally, without user intervention, independently of the water flow rate. When maximum water flow is present, the refrigerant entering the air-cooled condenser is already liquid, and the air-cooled condenser coil becomes a passive pass through. In this state, the outdoor fan is not needed and may shut down. When water flow is present, but less than that needed to fully condense the refrigerant, the air-cooled condenser simply handles the balance. In this state, the outdoor fan may operate at low speed. A variable speed fan drive will work well in this case, but is not required. When no water is flowing, the air-cooled condenser takes over entirely, and the Air Conditioning operates as originally configured.

[0079] This process is entirely passive, requiring no intelligent controls. No controls other than the existing Air Conditioning controls are needed. The only possible exception to this is a refrigerant temperature or pressure sensor, to control the outdoor condenser fan. Most Air Conditioning units have internal fan control that cycles or modulates the fan based on refrigerant temperature or pressure. This type of control will automatically shut down the outdoor fan when sufficient water is flowing.

[0080] In Air Conditioning equipment that is configured so the fan always runs when the compressor is running, this control function can be added. If it is not, the fan will run harmlessly whenever the compressor runs, even if water is flowing. If outdoor fan control is added, some additional energy will be saved by shutting down the fan when it is not needed.

[0081] The higher the water flow, and/or the lower the entering water temperature, the lower the Air Conditioning electrical consumption will be. This embodiment is especially advantageous in a laundry venue, where the water consumption rate is dynamic, varying constantly over a very wide range.

1. An energy efficient laundry facility comprising a space heating system, an air conditioning system, a plurality of clothes washers, a plurality of clothes dryers, a hot water storage tank supplying the washers, a source of cold water, a conduit means interconnecting the washers, dryers, storage tank, and cold water supply source, a plurality of dedicated heat recovery units associated respectively with said dryers and including heat exchangers and blowers which employ high temperature dryer exhaust air to heat water for supply to said storage tank, and a plurality of dedicated controller and temperature sensing means associated respectively with said heat recovery units for regulating the flow of hot water from the units to the storage tank.

2. An energy efficient laundry facility as set forth in claim **1** wherein each controller for a heat recovery unit directs hot water at a high temperature to the top of the storage tank and hot water at a substantially lower temperature to an intermediate point in the storage tank.

3. An energy laundry facility as set forth in claim **1** wherein conduit means are provided for directing hot water from the storage tank to the space heating system.

4. An energy efficient laundry facility as set forth in claim **1** wherein each heat recovery unit comprises a housing, a heat exchanger, a blower, a water circulation pump and a dedicated controller.

5. An energy efficient laundry facility as set forth in claim **1** wherein each heat recovery unit includes an exit water temperature sensor and a variable speed pump regulated by said controller.

6. An energy efficient laundry facility as set forth in claim **5** wherein each temperature controller regulates pump speed to maintain a pre-selected water discharge temperature.

7. An energy efficient laundry facility as set forth in claim **6** wherein each controller includes a dryer exhaust pressure monitor, a pressure controller and a variable speed blower drive.

8. An energy efficient laundry facility as set forth in claim **7** wherein each pressure controller varies the blower speed to maintain a desired dryer exhaust pressure.

9. An energy efficient laundry facility as set forth in claim **8** wherein each controller indicates when the blower is operating.

10. An energy efficient laundry facility as set forth in claim **9** wherein each controller operates the pump only when the blower is operating.

11. An energy efficient laundry facility as set forth in claim **10** wherein individual electrically operable shutoff valves are provided respectively for the hot water discharge ports and the warm water discharge ports.

12. An energy efficient laundry facility as set forth in claim **1** wherein a replaceable lint filter is disposed in the path of airflow through the unit.

13. An energy efficient laundry facility as set forth in claim **1** wherein each heat exchanger is of the counterflow type with the hot air entering the same adjacent the heated water exiting the same thus providing the hottest possible water.

14. An energy efficient laundry facility as set forth in claim **13** wherein each heat recovery unit has its heat exchanger and blower arranged to provide for substantially right angle air flow path therebetween resulting in a compact unit well suited to mounting atop a clothes dryer.

15. An energy efficient laundry facility as set forth in claim **14** wherein the clothes dryers have exhaust vents on their top surface, and wherein the recovery units have complementary air inlet openings on their lower surfaces for receiving heated air flow from the vents.

16. An energy efficient laundry facility as set forth in claim **1** wherein each heat recovery unit has separable heat exchanger sections and air handling sections, the latter including the blower, pump, controller etc.

17. An energy efficient laundry facility as set forth in claim **1** wherein a damper is provided for both directing air to the blower and directing air from the heat exchanger to an exhaust port, the damper having both normal and bypass positions.

18. An energy efficient laundry facility as set forth in claim **1** wherein each heat exchanger and blower are disposed in a linear configuration for connection with an exhaust header.

19. An energy efficient laundry facility as set forth in claim **1** wherein each recovery unit is mounted on top of a dryer and has a condensate collection pan disposed at a bottom portion in engagement with the top wall of the dryer.

20. An energy efficient laundry facility as set forth in claim **1** wherein each heat recovery unit includes a thin, flat, heat exchanger and blower arrangement which may be conveniently mounted on a wall behind the dryer, the unit being connected to the dryer discharge vent by conduit means.

21. An energy efficient laundry facility as set forth in claim **1** wherein a heat exchanger is provided upstream of a furnace or the like in the space heating system, and wherein conduit means is provided connecting the storage tank to said heat exchanger for preheating air entering the furnace or the like.

22. An energy efficient laundry facility as set forth in claim **1** wherein conduit means is provided connecting the storage tank with a hydronic space heating system for supply to base board heaters or the like.

23. An energy efficient laundry facility as set forth in claim **1** wherein a water to water heat exchanger is provided in a hydronic space heating system, and wherein conduit means is provided for connecting the storage tank to the heat exchanger.

24. An energy efficient laundry facility as set forth in claim **1** wherein a water to refrigerant heat exchanger is provided in the air conditioning system, and wherein conduit means is provided between the cold water source for the laundry and the heat exchanger for a supply of cold water to the heat exchanger and produces a reduction in the high side temperature of the heat exchanger, the cold water thereafter being employed in operation of the washers and dryers.

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