

HEAT RECOVERY SYSTEM

FIELD OF THE INVENTION

- 5 The present invention relates to a heat recovery system. In particular, the invention relates to a heat recovery system for hazardous and corrosive environments, such as fume cupboards.

BACKGROUND OF THE INVENTION

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Fume cupboards and other extraction systems remove air from a work space to ensure safe containment and removal of hazardous fumes. These work spaces are generally inside an air conditioned room, usually a laboratory.

- 15 To prevent undesirable vapours from contaminating the air inside a building housing a laboratory or hazardous work-room, an extractor fan continuously sucks fume-laden air out of the fume cupboard, maintaining a constant flow of air from the laboratory or work-room, through the cupboard, and out the exhaust ducting.

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To ensure safe containment and removal of the fumes is achieved a large volume of the conditioned air is removed. This conditioned air is either heated or cooled (depending on outside temperatures) to the desired room temperature, which is usually about 20°C. The volume of air that is consumed

- 25 by fume cupboards and other extraction systems causes considerable loading on air conditioning systems, resulting in considerable power consumption. This may be up to 5 times greater than the amount needed to air-condition a standard office space. There is also considerable capital cost in the air conditioning units as these units have to be considerably larger to handle the
- 30 increased loading of the fume cupboards.

Any heat recovered from fume cupboards will therefore provide for considerable

cost savings. However, providing a safe, efficient and cost-effective heat recovery system has proved difficult. This is due to the corrosive and hazardous environment in which any such system will operate and the need to ensure that there is no contamination of clean air entering the building with extracted hazardous materials. User safety is a particularly important aspect that must be achieved with any system recovering heat from a fume cupboard or other extraction system.

A review article by VanGeet and Reilly (Heat Recovery for Laboratories, *Ashrae Journal*, March 2006, pages 45 – 53) discusses these issues and notes that contamination is an issue of particular concern.

GB 1354502 discloses a heat exchanger comprising a plurality of plates formed of a plastics material such as fluorocarbon polymers, hdpe or polypropylene. The plates are provided with spacers forming seals between adjacent plates, which define passages for fluid passing between spaced-apart areas of the plates. A multipass system is described. However, this system does not address the issue of leakage and possible contamination of the clean air entering the building.

A need therefore exists to provide a safe, cost effective and practical heat recovery system for hazardous and corrosive environments, in particular for fume cupboards.

SUMMARY OF THE INVENTION

In a first aspect, the present invention provides a heat recovery system comprising

a heat exchanger comprising

a housing having an air supply inlet, an air supply outlet, an exhaust inlet and an exhaust outlet; and

a plurality of panels located within the housing, wherein the panels are spaced apart from each other so as to form a

- plurality of first channels extending through the heat exchanger in a first direction,
- each panel comprises substantially parallel walls separated by a plurality of spacers so as to form a plurality of second channels extending through each panel in a second direction,
- spaces between the panels in the second direction are closed, and
- the supply air outlet is in communication with the exhaust air inlet;
- a fume cupboard having an exhaust means, the exhaust means being in communication with the exhaust outlet of the heat exchanger; and an air conditioner having a supply air intake means.

Preferably, the arrangement is such that air passing through the first channels passes in and out of the housing through the supply air inlet and the supply outlet.

Preferably, the arrangement is such that air passing through the second channels passes in and out of the housing through the exhaust inlet and the exhaust outlet.

Preferably, the supply air intake means is adapted to blow supply air through the heat exchanger.

Preferably, the supply air intake means includes a fan.

Preferably, the exhaust means is adapted to suck exhaust air through the heat exchanger.

Preferably, the exhaust means includes an exhaust fan.

Preferably, the housing of the heat exchanger further comprises a divider extending therethrough, which separates the housing into two separate portions.

Preferably, the heat exchanger further comprises a closure means, such as plenum box.

Preferably, the housing is formed of a corrosion resistant plastics material.

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Preferably, the panels are formed of flute board, more preferably polypropylene flute board.

Preferably, the housing is provided with a plurality of means, such as slots, to position the plurality of panels within the housing.

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In a second aspect, the present invention provides a heat exchanger comprising

a housing comprising an exhaust air inlet, an exhaust air outlet, a supply inlet and a supply outlet; and
a plurality of panels located within the housing; wherein
the panels are spaced apart from each other so as to form a plurality of first channels extending through the heat exchanger in a first direction;
each panel comprises substantially parallel walls separated by a plurality of spacers so as to form a plurality of second channels extending through each panel in a second direction; and
spaces between the panels in the second direction are closed.

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In a third aspect, the present invention provides a method of heat exchange comprising the steps of:

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connecting a heat exchanger as described above with a fume cupboard and with an air conditioner,
blowing a supply air through the heat exchanger in a first direction,
sucking an exhaust air through the heat exchanger in a second direction.

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This brief summary of the invention broadly describes the features and advantages of certain embodiments of the invention. Further features and advantages will be described in the detailed description of the invention that

follows.

Novel features that are believed to be characteristic of the invention will be better understood from this detailed description when considered in connection
5 with the accompanying drawings. However, the accompanying drawings are intended to help illustrate the invention or assist with understanding the invention, and are not intended to define the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

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Figure 1: shows a schematic cross-sectional view of a fume cupboard installation, incorporating a heat recovery system according to one aspect of the present invention.

15 Figure 2: shows a schematic plan view of the fume cupboard installation shown in Figure 1.

Figure 3: shows a perspective view of a heat exchanger according to one aspect of the present invention.

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Figure 4: shows a schematic perspective view of the heat exchanger housing with plates.

25 Figure 5: shows a schematic plan view of the heat exchanger housing shown in Figure 4.

Figure 6: shows a schematic side view of the heat exchanger housing shown in Figure 4.

30 Figure 7: shows a schematic cross-sectional view of a flute board plate or panel used in the heat exchanger of the present invention.

Figure 8: shows a schematic cross-sectional view of the heat exchanger

housing shown in Figure 3.

Figure 9: shows the test results provided in Table 1.

5 DETAILED DESCRIPTION OF THE INVENTION

The heat recovery system of the present invention comprises a heat exchanger that recovers heat from the air flowing through and out of a fume cupboard.

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Laboratories and hazardous work-rooms are usually maintained at a comfortable temperature for people working in them. This means that the air drawn into a fume cupboard often has been heated or cooled, depending on the local climate. The heat exchanger of the present invention uses the fume
15 cupboard's exhaust to pre-condition fresh air drawn into a building by the building's air-conditioning system.

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Heat exchangers often comprise metals because metals readily conduct heat. Metal heat exchangers are suitable in general exhaust applications but the metals required to withstand the demanding corrosive fume cupboard
environment are prohibitively expensive.

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The heat exchanger of the present invention makes use of chemically resistant plastics materials not traditionally used in heat exchangers.

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The flow volumes and temperatures associated with fume cupboards mean that the relatively low thermal conductivity of these non-traditional materials did not necessarily result in poor heat exchanger effectiveness. The effects of the thermal conductivity of the relatively thin materials are negligible when
compared to the heat transfer coefficients of the air streams. These plastics
materials are also less expensive than conductive metals.

In one preferred embodiment, the heat exchanger of the present invention is a

- plate heat exchanger. In this embodiment, the heat exchanger makes use of an additional "pass", whereby one of the air streams "passes" through/over the plates twice. This arrangement, which is described in more detail below, is a cross counter flow configuration. Cross counter flow heat exchangers provide better performance than cross flow heat exchangers but still maintain the compactness of the cross flow heat exchanger. This arrangement also provides additional gains in effectiveness as the flow through the two passes has a higher velocity. This increases the heat transfer coefficient.
- It should be appreciated, however, that in other embodiments of the invention, the heat exchanger may be a single pass (cross flow) heat exchanger, and in other embodiments, the heat exchanger may be configured to allow for multiple passes, such as three or more passes.
- The configuration of heat recovery system enables the air to be blown and sucked through the heat exchanger as follows. The inlet of the fume cupboard exhaust fan is connected on to the outlet of the heat exchanger and the supply air fan outlet is connected to the inlet of the heat exchanger. This means that the supply air is blown into the heat exchanger (positive pressure) and the fume cupboard air is sucked through the heat exchanger (negative pressure). This provides a fail-safe type system, which in the case of seal failure or damage to the heat exchanger, means that the fume cupboard air stream cannot contaminate the supply air stream.
- Referring now to the accompanying drawings, Figure 1 shows a schematic cross-sectional view of a heat recovery system 1, incorporating a heat exchanger 2 and an air conditioning unit 3.
- The heat recovery system 1 also comprises a fume cupboard 6, which may be a VAV (variable air volume) or CAV (constant air volume) fume cupboard. The fume cupboard incorporates an exhaust 4 and exhaust fan 5.

Between the fume cupboard 6 and the heat exchanger 2 is duct 7, which is preferably insulated. Between the heat exchanger 2 and the exhaust fan 5 is a

duct 8.

As shown in Figure 2, the air conditioning unit 3 comprises an air intake 9 and a supply air fan or air handling unit 10. Between the supply air fan 10 and the heat exchanger 2 is a duct 11. Referring again to Figure 1, duct 12 is provided between the heat exchanger 2 and the air conditioning unit 3.

Figure 3 shows a perspective view of a heat exchanger 2 according to one aspect of the present invention. The heat exchanger 2 is constructed of corrosion resistant plastics.

The heat exchanger comprises a housing 13, which in one embodiment may be manufactured of rigid PVC. The housing 13 comprises an exhaust inlet 14, an exhaust outlet 15 and a plenum box 16.

As shown in Figure 4, the housing 13 is preferably also provided with a dividing plate 17, which divides the space in the housing 13 into two separate portions.

As is shown in Figures 4 to 6, a plurality of plates or panels 18 (hereafter panels) is provided within the housing 13 of the heat exchanger 2. The housing 13 preferably has slots (not shown) cut into it to hold the panels 18 in place.

These slots space the panels 18 apart from each other, so that in a first direction A spaces or channels 19 are provided between each of the panels 18.

In a second direction B, the spaces between the panels 18 are closed, for example by use of plastic strips 20. These strips 20 ensure that no air can pass between the panels 18 in direction B.

In one preferred form of the invention, the panels 18 are approximately 5.2 mm wide and the channels 19 are approximately 4.8 mm wide.

Preferably, the panels 18 are constructed from polypropylene flute board. As shown in Figure 7, the flute board comprises parallel walls 21 separated by a

plurality of spacers 22, so that the flute board comprises a series of channels 23 extending therethrough.

5 The joints between the flute board panels 18 and the PVC housing 13 are sealed or glued together using a vinyl ester resin. This provides an air tight, corrosion resistant seal.

In use, the heat recovery system of the present invention operates in the following manner.

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Air extracted from the fume cupboard 6 (air stream C) is sucked through the duct 7 and enters the heat exchanger 2 via the exhaust inlet 14. Air stream C moves through the housing 13, and passes through the channels 23 in the panels 18. Air stream C then exits the heat exchanger 2 via exhaust outlet 15.

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At the same time, fresh air (air stream D) is introduced into the air conditioning unit 3 via the inlet 9. Air stream D is blown through the duct 11 and enters the heat exchanger 2 via supply inlet 24, shown in Figure 8. Air stream D moves through the heat exchanger 2 in the direction indicated by arrows D in Figure 8, passing over the panels 18.

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Air stream D then exits the heat exchanger 2 via supply outlet 25 and enters duct 12 of the air conditioning unit 3. From there it enters the air conditioning system of the building.

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During this process, the heat conducting plastic panels 18 will transfer heat from one air stream to the other, without the air streams themselves mixing together. The direction of the heat transfer will depend on the local climate. If the air exiting the fume cupboard is warm, it will transfer heat to the cooler air that is to enter the air conditioning unit. If the air exiting the fume cupboard is cool, it will absorb heat from the warmer air that is to enter the air conditioning unit.

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In one preferred embodiment, the supply air (air stream D) enters the system through the supply inlet 24 that is located on the exhaust air outlet side 15.

This improves performance of the system as this makes more efficient use of the temperature difference. This is because the arrangement is a cross

5 counter flow heater exchanger rather than a cross parallel flow heat exchanger.

As will be apparent, the heat exchanger of the present invention is a cross counter flow heat exchanger. By this it is meant that one of the air streams

10 "passes" through/over the plates twice. Preferably, the air stream that undergoes the additional pass is the supply air (air stream D) as this passes between the flute boards.

As well as allowing for an additional pass, dividing plate 17 also provides

15 additional support for the flute board panels 18. The dividing plate 17 creates two air ways for the two passes, and also acts as a support between the flute board panels 18.

The inlet of the fume cupboard exhaust fan 5 is connected on to the exhaust outlet 15 of the heat exchanger by the duct 8. The outlet of the supply air fan 10 is connected to the supply inlet 24 of the heat exchanger. This provides a fail-safe type system, which means that the fume cupboard air stream cannot contaminate the supply air stream and hence ensure no contaminants make their way into the building. This is a significant safety feature of the system.

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EXPERIMENTAL RESULTS

Energy Recovery

For a typical mid-sized fume cupboard, prototype results show the heat exchanger recovers up to 80% of the heat that would otherwise be lost through the fume cupboard exhaust.

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Performance Testing

A test heat exchanger according to the present invention was setup inside a refrigerated shipping container. The container's heavy insulation minimised temperature fluctuations, providing a repeatable test environment. A standard fume cupboard and a typical air conditioning system were installed. The fume
 5 cupboard's exhaust duct and the air-conditioner's intake duct were connected to the test heat exchanger.

Testing was conducted to determine the heat exchanger's effectiveness performance. These tests were carried out across a range of flow rates and
 10 with equivalent airflow rates for each air stream of the heat exchanger.

To determine the airflow rates for each test and to ensure that the airflow rates for each air stream are equivalent, velocity tests were conducted on each air stream. The velocity tests were conducted using the industry
 15 standard log-Tchebycheff method. The average velocity was calculated and the airflow rates determined by multiplying the velocity and the cross sectional area of duct.

Performance is dependent on turbulent flow inside the heat exchanger, which
 20 meant its performance may be affected by the rate of air flow. In a medium-sized fume cupboard the flow varies from 100 litres per second, when the cupboard door is closed, to about 600 litres per second when the door is open.

25 Establishing the effectiveness of the heat exchanger itself is calculated based on the inlet and outlet temperatures. The equation for effectiveness, P, is:

$$P = (M_{MA} \times C_p \times (T_{MA \text{ out}} - T_{MA \text{ in}})) / (M_{FC} \times C_p \times (T_{FC \text{ in}} - T_{MA \text{ in}}))$$

where M_{ma} is the mass flow rate of the supply air, M_{FC} is the fume cupboard
 30 exhaust air mass flow rate, C_p is the specific heat capacity of air, $T_{ma \text{ out}}$ is the temperature of the supply air coming out of the heat exchanger and going into the air conditioning system, $T_{ma \text{ in}}$ is the temperature of the supply air that is coming from outside going into the heat exchanger and T_{FC} is the temperature

of the fume cupboard exhaust air.

In all of these tests C_p is constant and cancels out in the equation above, and as the volume flow rates are matching the mass flow rates also cancel out

5 leaving:

$$P = (T_{MA \text{ out}} - T_{MA \text{ in}}) / (T_{FC \text{ in}} - T_{MA \text{ in}})$$

This is the equation used in determining the effectiveness in the results shown below.

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Each test was conducted with the space environment being maintained at 30°C, and the incoming supply air temperatures are based on the outside environments air temperature which varies with the weather conditions and the time of day. To deal with this a data logger was used to simultaneously

15 record the temperature readings. For all tests that were conducted on heat exchanger prototypes, the sampling rate has been set at 1 sample per second and the logging rate is every 5 samples. This means the information being logged is an average of the 5 sample readings.

20 The results of the effectiveness from the testing are shown in Table 1 below. Shown is the maximum, minimum and average of each test run. Figure 9 also shows a chart of these results.

Table 1

Maximum Effectiveness	Average Effectiveness	Minimum Effectiveness	Average Flow rates (l/s)
0.549	0.5315	0.521	600
0.56	0.553	0.545	495
0.59	0.58	0.57	385
0.653	0.629	0.617	291.4
0.717	0.697	0.676	191
0.841	0.826	0.799	78.2

These results show the test heat exchanger would recover between 50% and 80% of the waste heat.

Chemical Resistance of Heat Exchanger Panels

- 5 The plastics material of the heat exchanger panels was tested to determine if it could withstand the potentially dangerous fume cupboard environment and to determine whether the system would continue to safeguard the buildings occupants in the event of an unforeseen, catastrophic failure.
- 10 Standard test ASTM D543 – 06 was used, with some modifications to accommodate the effect of chemical vapours.

Testing involved subjecting samples of the heat exchanger in various acids, alkalis, and solvents. The test involved soaking the samples in liquids.

- 15 Another series of tests uses vapours instead of liquids. Test results indicated that the heat exchanger's chemical resistance would be comparable with that of existing fume cupboards.

- 20 Eight reagents were chosen to represent 3 classes of chemicals: acids, alkalis, and solvents. All solutions were of technical grade or greater purity, made with freshly prepared distilled water.

Table 1: List of chemicals and their preparation procedures

Chemical	Type	Preparation procedure
Acetone	Solvent	From stock solution
Dichloroethane (ethylene dichloride)	Solvent	From stock solution
Chromic acid (30%)	Acid	Dissolve 364g of chromic trioxide (CrO ₃) in 850mL of water
Nitric acid (10%)	Acid	108mL (153g) HNO ₃ (specific gravity 1.42) to 901mL of water
Phenol solution (5%)	Solvent	dissolve 47g of carbolic acid crystals in 950mL of water

Sodium hydroxide solution (10%)	Alkali	dissolve 111g of NaOH in 988mL of water
Sulfuric acid (30%)	Acid	slowly add 199mL (366g) of H ₂ SO ₄ (sp gr 1.84) to 853mL of water
Toluene	Solvent	From stock solution

Each beaker was filled with 500mL of a chemical reagent from Table 1. Two test specimens were used: one for direct liquid exposure (i.e. immersed), and the other for vapour exposure (i.e. suspended by corrosion resistant wiring).

- 5 The suspended specimen was approximately 10-15mm above the liquid surface. The immersed samples were tested in the worst case scenario in which the material was exposed to the chemical directly, whereas the suspended samples have more similarities to the 'fume cupboard' condition where the materials were only in contact with the vapour phase or diluted
- 10 condensate of the chemicals.

The results from the testing show that the assembly and materials to be suitable for use in fume cupboard environments and that the heat exchanger can be expected to have a similar life span to PVC fume cupboards.

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The vinyl ester resin used to join the component parts of the heat exchanger should be of a chemically resistant grade.

The present invention and its embodiments have been described in detail.

- 20 However, the scope of the present invention is not intended to be limited to the embodiment described in the specification. Modifications and variations may be made to the disclosed embodiment without departing from the scope or essential characteristics of the present invention.

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CLAIMS

1. A heat recovery system comprising
a heat exchanger comprising
- 5 a housing having an air supply inlet, an air supply outlet, an exhaust inlet and an exhaust outlet; and
a plurality of panels located within the housing, wherein
the panels are spaced apart from each other so as to form a
plurality of first channels extending through the heat exchanger
10 in a first direction,
each panel comprises substantially parallel walls separated by a
plurality of spacers so as to form a plurality of second channels
extending through each panel in a second direction,
spaces between the panels in the second direction are closed,
15 and
the supply air outlet is in communication with the exhaust air inlet;
a fume cupboard having an exhaust means, the exhaust means being
in communication with the exhaust outlet of the heat exchanger; and
20 an air conditioner having a supply air intake means.
2. The heat recovery system as claimed in claim 1, wherein the
arrangement is such that air passing through the first channels passes in and
out of the housing through the supply air inlet and the supply outlet.
- 25 3. The heat recovery system as claimed in claim 1 or claim 2, wherein the
arrangement is such that air passing through the second channels passes in
and out of the housing through the exhaust inlet and the exhaust outlet.
- 30 4. The heat recovery system as claimed in any one of claims 1 to 3,
wherein the supply air intake means is adapted to blow supply air through the
heat exchanger.
5. The heat recovery system as claimed in any one of claims 1 to 4,

wherein the supply air intake means includes a fan.

6. The heat recovery system as claimed in any one of claims 1 to 5,
wherein the exhaust means is adapted to suck exhaust air through the heat
5 exchanger.

7. The heat recovery system as claimed in any one of claims 1 to 6,
wherein the exhaust means includes an exhaust fan.

10 8. The heat recovery system as claimed in any one of claims 1 to 7,
wherein the housing of the heat exchanger further comprises a divider
extending therethrough, which separates the housing into two separate
portions.

15 9. The heat recovery system as claimed in any one of claims 1 to 8,
wherein the heat exchanger further comprises a closure means.

10. The heat recovery system as claimed in claim 9, wherein the closure
means is a plenum box.

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11. The heat recovery system as claimed in any one of claims 1 to 10,
wherein the housing is formed of a corrosion resistant plastics material.

12. The heat recovery system as claimed in any one of claims 1 to 11,
25 wherein the panels are formed of flute board.

13. The heat recovery system as claimed in claim 12, wherein flute board
is polypropylene flute board.

30 14. The heat recovery system as claimed in any one of claims 1 to 13,
wherein the housing is provided with a plurality of means to position the
plurality of panels within the housing.

15. The heat recovery system as claimed in claim 14, wherein the housing is provided with a plurality of slots to position the plurality of panels within the housing.

- 5 16. A heat exchanger comprising
a housing comprising an exhaust air inlet, an exhaust air outlet, a
supply inlet and a supply outlet; and
a plurality of panels located within the housing; wherein
the panels are spaced apart from each other so as to form a plurality of first
10 channels extending through the heat exchanger in a first direction;
each panel comprises substantially parallel walls separated by a plurality of
spacers so as to form a plurality of second channels extending through each
panel in a second direction; and
spaces between the panels in the second direction are closed.
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17. A method of heat exchange comprising the steps of:
connecting a heat exchanger as described above with a fume cupboard
and with an air conditioner,
blowing a supply air through the heat exchanger in a first direction,
20 sucking an exhaust air through the heat exchanger in a second direction.