2005 Annual Report

Open Absorption System for Cooling and Air Conditioning using Membrane Contactors

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SUMMARY

The results obtained so far in the *MemProDEC* project concern questions related to the selection of materials, in particular to corrosion, and the design of the AHU prototype and its components. Regarding the problem of corrosion of metallic components by aqueous alkali halide solutions, it has been found that even alloys known for their corrosion resistance are corroded by the selected desiccant solution at ambient temperatures, in the presence of oxygen. To solve this problem in the prototype, polymeric materials shall be used for the main components. This solution permits innovative designs for the components of the prototype, and a high modularity in terms of manufacturing and assembling as well. The configuration chosen for the first complete AHU prototype assumes an all-air air conditioning system: The AHU supplies conditioned air, at the conditions required by the conditioned space, at an expected thermal COP in the range of 0.5 to 0.7 with a regenerator water supply temperature of 60 °C. Calculations show that other configurations may deliver dry air and cold water, or cold water alone, at similar thermal COPs.

Project Objectives

General Objectives

In the *MemProDEC Project,* it is envisaged to develop, build and test experimentally in the laboratory a conceptual design of a new type of air handling unit (AHU), operating with a liquid desiccant. The AHU shall be autonomous, i.e. shall not require additional mechanical refrigeration. It shall be thermally driven at temperatures below 80 °C. Waste heat sources, solar thermal collectors, district heating plants and cogeneration systems are able to provide thermal energy at this temperature level. The use of district heating in Summer is especially advantageous since the network loads are, in general, well bellow their nominal capacity. District heating plants burning urban waste, on the other hand, have to dissipate generated heat through cooling towers in Summer, particularly since they must continue to burn waste, even without demand from the network.

The AHU shall operate as an open absorption system (atmospheric pressure), although no direct contact takes place between the air and the liquid desiccant. Air and desiccant are contacted through adequate membranes, thus avoiding desiccant aerosols and solving the attending corrosion and potential health problems. Furthermore, confining the desiccant also permits a reduction of the amount of desiccant required in relation to common open systems. A reduction of the quantity of desiccant, besides reducing costs, reduces the start-up times as well. This is also an important aspect to consider when the system has to cycle at part-load.

This type of AHU shall reduce electric energy demand for air conditioning and may contribute to improve the economics of district heating networks by providing new customers for the excess heat available in summer. On the other hand, solar thermal energy becomes a real alternative, since the driving energy is required at a level well bellow that of traditional, closed absorption systems.

Development of membrane contactor technology for air-conditioning processes

Membranes, in particular polymeric membranes, are increasingly used in many processes in various industrial fields. Typical examples are water purification by reverse osmosis and fuel cells.

In building systems, particularly in regard to comfort and indoor air quality, developments are under way to introduce membrane-based devices into the market. This development has in view applications where traditional heat recovery devices, the so-called HRVs[1] (*ASHRAE* nomenclature) are to be replaced by ERVs[2], which, besides heat recovery, allow for humidity recovery between the exhaust and supply air streams as well. The application of ERVs is considered advantageous in both cold (northern) climates as well as in hot and humid ones (Dobbs et al., 2005, Lam et al., 2005). The membranes mostly used in the construction of ERVs are ionomer (ion containing polymer) type membranes. Ionomer membranes are mostly hydrophilic, and the transport of water molecules across the membrane is ion supported (SO_3^- for example).

In this project, and contrary to ERVs, which contact two gaseous streams, the membrane contactors shall contact a gaseous stream with a liquid (water or a desiccant solution) one. Hydrophilic membranes are less suitable for this process than hydrophobic ones. The transport of water molecules takes place as vapour diffusing through the micropores of the membrane. The characterization of the membranes considered is discussed later.

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[1] **H**eat **R**ecovery **V**entilator

[2] **E**nergy **R**ecovery **V**entilator

Liquid desiccant solutions, particularly the aqueous solutions of alkali halides, corrode most metals and their alloys, especially in the presence of oxygen. The design of the contactors for this project considers alternative materials (industrial polymers) for their construction. The objective here is to combine low cost, high availability and simplicity of construction. Further cost reductions may be attained by simplifying contactor design according to function. Three stream contactors are necessary for the absorber and desorber, and for evaporative coolers delivering cold water to the air conditioning system. Evaporative coolers for internal use in the AHU, on the other hand, may be manufactured as two stream types.

Development of autonomous open-absorption AHU configurations

Central air conditioning systems may condition the air either in a central AHU before delivery to the conditioned space (all air system), condition it locally in terminal units, with chilled water delivered from a central plant, or by varied combinations of these two limiting configurations. Delivering cold water from a central plant to terminal units (induction units, fan-coils and cooled ceilings, for example) is generally advantageous in terms of running costs, since moving water is in general less energy demanding than moving air, and the whole plant is more compact.

Autonomous AHUs based on liquid desiccant and membrane contactors can be designed for both limiting configurations (all air and only chilled water) and for every possible combination requiring both dry air and cold water. As shall be explained later, an AHU for combined demand of dry air and cold water is more complex and may be less efficient than for the two limiting cases. Due to the budget limitations in this project, only an all air configuration shall be built and tested in the laboratory, although the basic designs for the other combinations have been considered.

Work Performed and Results

The work performed in 2005 concentrated essentially on two main areas of the technology development: Selection, testing and characterization of materials, and component and plant design. The principal results of this work shall be presented and discussed in the following.

1. Selection, testing and characterization of materials

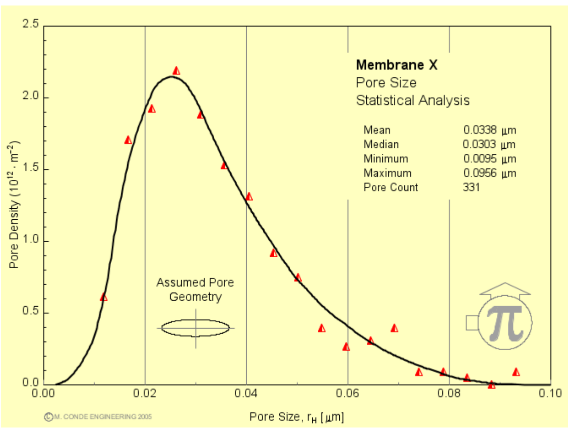

Figure 1: Pore size (hydraulic radius) distribution as determined by statistical analysis of an SEM image of the membrane surface.

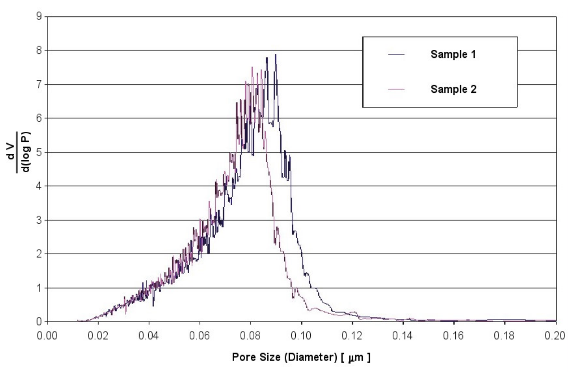

Figure 2: Pore size distribution as determined by dynamic measurement of permeability (provided by the manufacturer).

Preliminary studies of membranes and membrane materials have indicated that only hydrophobic microporous membranes would be suitable for the membrane contactors in the application envisaged in this project. The characterization of the selected membrane, on the basis of manufacturer's data (SEM images and permeation tests) shows that it should be safe for application in the range of temperatures required and for the liquids considered. A residual risk remains due to pores of a size much larger than typical (Figures 1 & 2).

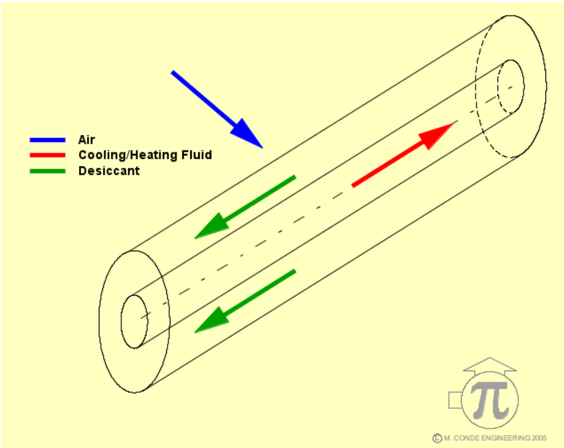

Figure 3: schematic representation of a three stream membrane contactor.

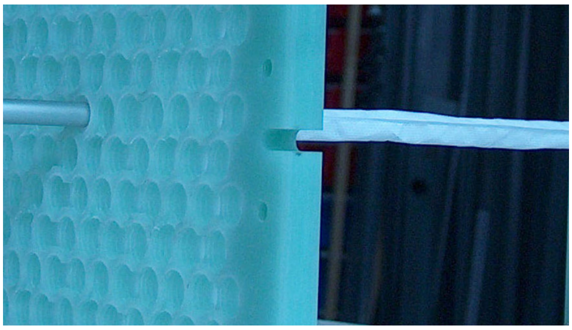

Figure 4: Partial view of a membrane tube, built into the first contactor prototype. The seam of the membrane tube is clearly observable.

A preliminary design of a three-stream membrane contactor, conceived as a coaxial construction, with a metallic tube in the center, and an annulus defined by a membrane tube, is depicted schematically in Figure 3. Membrane tubes, in the range of diameters required, are not available on the market, except for high cost medicinal products (used in heart surgery, for example). Membrane tubes were thus manufactured out of membrane film by welding (sealing process), at the *Empa Protection and Physiology Laboratory.*

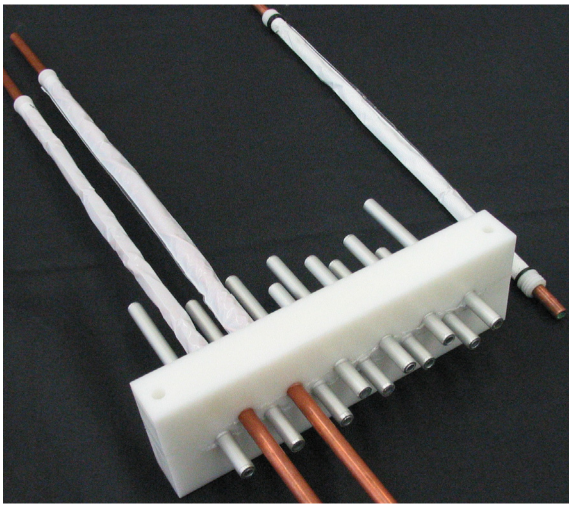

Figure 5: Details of a redesigned membrane contactor frame that facilitates mounting and removal of the membrane tube assemblies (to the right of the frame).

Although the seams produced by this process, Figure 4, were rather resistant, they could hardly be fitted in the contactor without damage. In the experiments, the stability of the membrane tubes manufactured by this process, from the selected material, could not be warranted. Even a redesigned contactor frame, Figure 5, that would facilitate mounting and removal of membrane assemblies, would still present similar problems.

On the other hand the metallic tube at the center of the contactor would be exposed to the desiccant in the presence of oxygen. Experiments carried out with tubes of three different copper-nickel alloys, besides copper, have shown that even high nickel content alloys, such as the *CW354H (CuNi30Mn1Fe)* alloy, would be significantly corroded under the expected operating conditions. Figure 6 shows three sets of samples of the following alloys: *CuNi10Fe1,6Mn, CuNi10Fe1Mn,* and *CuNi30Mn1Fe,* in this order from right to left. One sample is exposed to the air (front), a second one is immersed in desiccant solution, in open Petri dishes in direct contact with air (middle row), and the third one is also immersed in desiccant solution inside a closed vial. It is visible in Figure 6 that the samples exposed in open Petri dishes have been significantly corroded at room temperature, with corrosion intensity increasing from left to right. This result has lead to the search for other kinds of materials, that should avoid the risks of corrosion, would permit constructive geometries other than the concentric annulus, and be significantly cheaper and easier to work with than the high nickel content alloys. Materials satisfying all these conditions are polymeric materials, for example. They are cheaper than most alloys that might be chosen for this application, and are suitable for the operating temperatures of the application. The contactors and heat exchangers of the prototype shall be made out of polymer material.

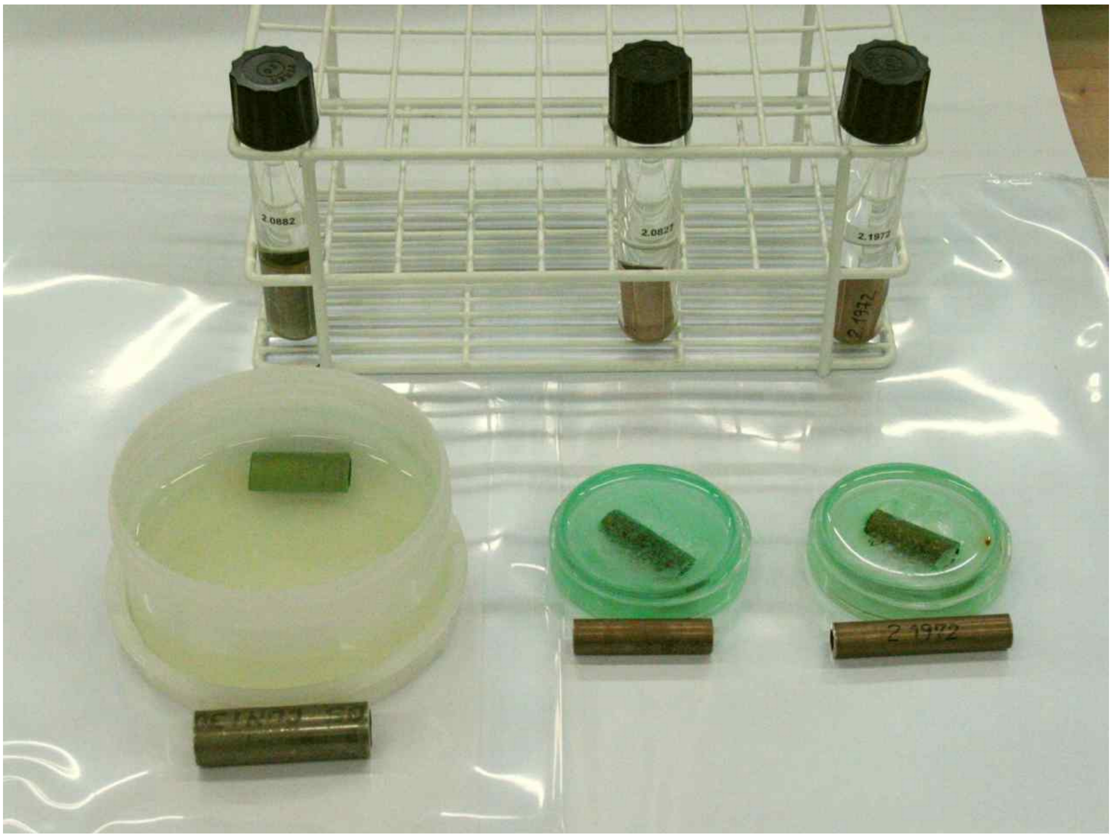

Figure 6: Corrosion tests on 'corrosion resistant' copper-nickel alloys at EMPA: As seen in the middle row, even high nickel content alloys are corroded by the liquid desiccant solution in the presence of oxygen, at room temperature. Note that the desiccant was allowed to remain in equilibrium with ambient air. The samples immersed in desiccant, in the absence of oxygen, are not corroded (back row). Samples exposed to air only at room temperature (front row) show no signs of corrosion.

2. Thermodynamic design of the AHU

For the design of the Air Handling Unit the following design conditions have been chosen (Summer Case):

Process Air Data for the Design Case						
		OA(1)	SA(2)	RA(3)	EA(4)	Units
Dry-Bulb Temperature	T_{DB}	32.0	18.0	26.0		°C
Relative Humidity	φ	40.0	55.0	40.0		%
Humidity Ratio	ω	11.958	7.076	8.403		$g.kg_{DA}^{-1}$
Barometric Pressure	P	101.325	101.325	101.325	101.325	kPa

(1) Outside Air; (2) Supply Air; (3) Return Air; (4) Exhaust Air.

The desiccant solution is assumed to operate between the salt mass fractions of 0.40 and 0.42. On the basis of these conditions, a prototype of the all-air AHU type has been designed. As depicted in Figure 7, an AHU of this type requires the following main components: A conditioner (3), a regenerator (7), two evaporative coolers (4 & 9), two air-air heat recovery heat exchangers (6 & 8), and a desiccant solution heat exchanger (5).

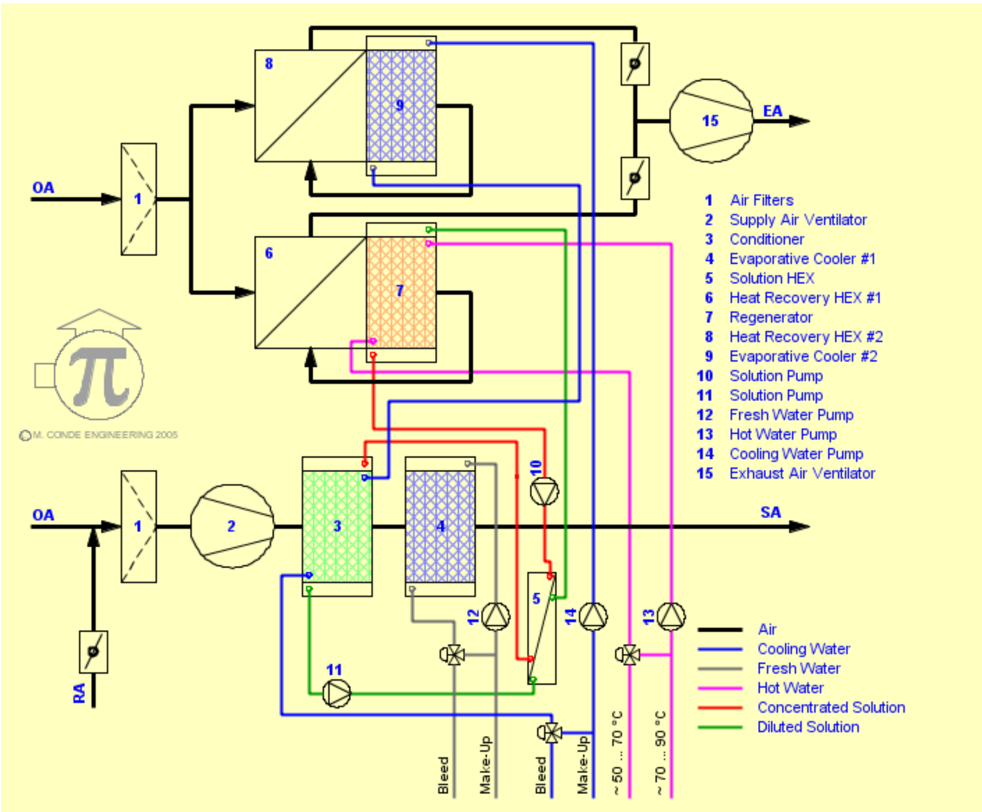

Figure 7: Schematic representation of an AHU for an all-air air conditioning system. The main components of the unit are the membrane contactors 3, 4, 7 and 9, and the heat exchangers 5, 6 and 8, besides filters, fans and pumps.

The prototype has been designed for a total (latent + sensible) capacity of 1 kW. The calculations let us expect a thermal COP in the range of 0.5 to 0.7, for a regeneration water inlet temperature of 60 °C.

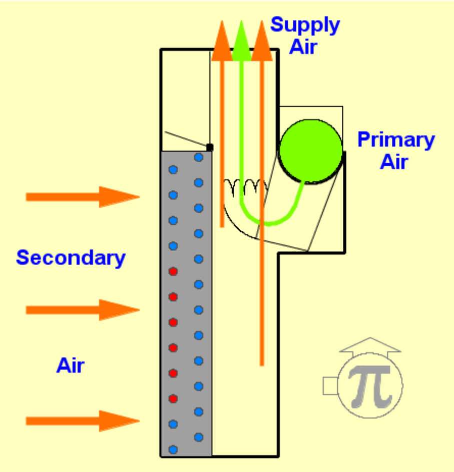

Figure 8: Schematic of an induction unit.

System calculations, though not a complete design as for the case above, were also carried out for an AHU delivering the same 1 kW total capacity, combining dry air and cold water. The AHU is considered to deliver dry air and cold water to induction units.

The induction units (Figure 8) operate with a 6:1 secondary/primary air ratio. The primary air is supplied at the same SA conditions stated above (the actual supply air conditions result from the mixing of primary and cooled secondary air in this case). This might as well apply to a system operating with cooling ceilings. Figure 9 shows a schematic representation of such an AHU. These system calculations would let us expect a thermal COP in the range 0.3 to 0.6, for a regeneration water inlet temperature of 60 °C. As may be inferred from Figure 9, an AHU delivering dry air and cold water is more complex than in the case of an all-air system. This complexity leads as well to a lower COP. An AHU delivering cold water only, might again be simpler and more efficient, though this case shall not be considered in this phase of the project.

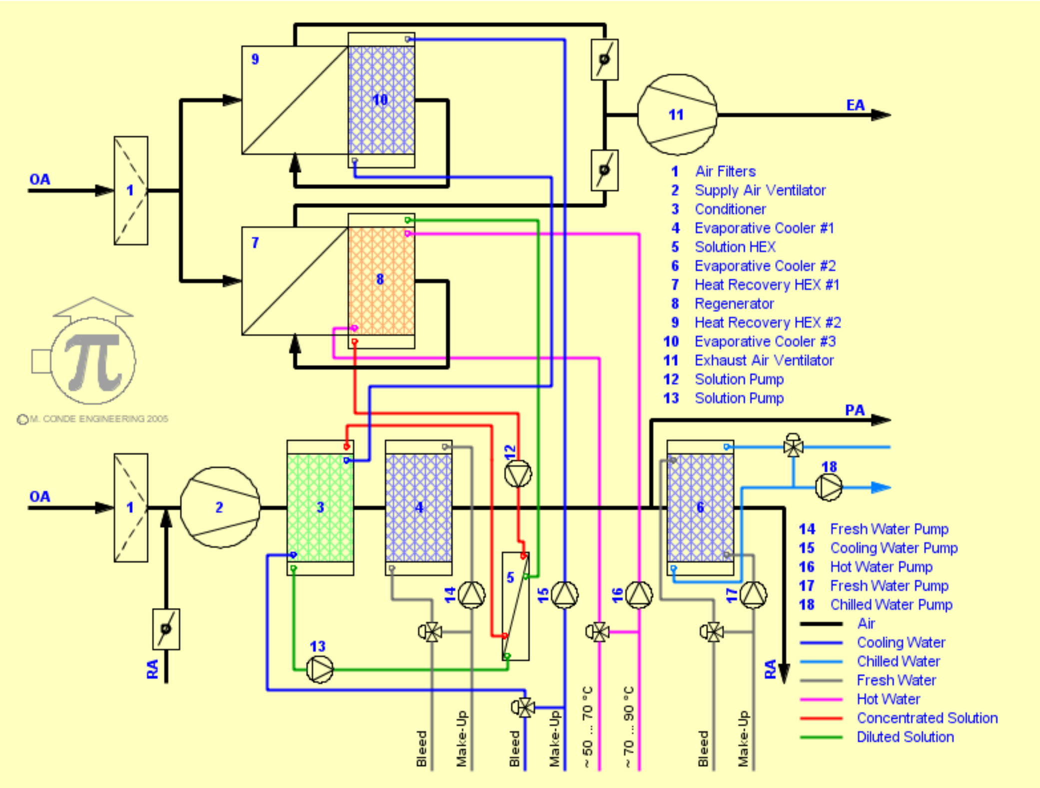

Figure 9: Schematic representation of an AHU for an air conditioning system with terminal units (induction units, cooled ceilings, for example). The main components of the unit are the membrane contactors 3, 4, 6, 8 and 10, and the heat exchangers 5, 7 and 9, besides filters, fans and pumps.

Cooperation at national level

This project is being carried out jointly by *M. Conde Engineering* and *Empa*. Two industrial partners *(Soltherm AG and Zehnder Comfosystems AG)* shall make small contributions in terms of components, and the *Swiss District Heating Association* participates as an observer.

International cooperation

There is no international cooperation in this phase of the project.

Assessment 2005 and outlook 2006

The research on materials and processes from the preliminary phase has been continued in the second half of the year (the project started in July 2005), and is practically concluded. Although our initial approach, building an innovative AHU based upon conventional component designs (tube-bundle heat and mass exchangers), had to be abandoned due to the corrosion problems and impracticability of the three stream membrane tube assemblies described, the solution now developed is not only innovative, but shall permit considerable gains in material costs and system compactness. The components (membrane contactors and heat exchangers) shall be built as an assembly of individual elements, an element being a fully functional contactor or heat exchanger. This innovative, elementwise construction offers an enormous flexibility in terms tailoring AHUs for any specific application (in contrast to conventional units covering ranges of capacities).

The actual prototype AHU shall be built and tested in the laboratory in 2006. The experience gained in the experimental testing and analysis of the AHUs performance shall be the basis to decide on further phases of development, since the unit, as developed in this phase 1, is a bare bones machine, without an integrated control system and is designed for a very small capacity.

References

[1] G. M. Dobbs et al.: ***Recent Advancements in High Latent Recovery Effectiveness Membrane Flat Plate Heat Exchangers for Air-to-Air Energy Recovery from Ventilation Air***, ASHRAE Annual Meeting, Denver - USA, June 2005.

[2] K. P. Lam et al.: ***Simulation of the Effect of an Energy Recovery Ventilator on Indoor Thermal Conditions and Systems Performance***, Proceedings 9th IBPSA Conference, Montreal - Canada, August 2005.