INNOVATIONS IN VENTILATION TECHNOLOGY

21ST ANNUAL AIVC CONFERENCE
THE HAGUE, NETHERLANDS, 26-29 SEPTEMBER 2000

Evaporative cooling and sorption assisted dehumidification with liquid salt solutions

Sönke Biel, Fritz Steimle

Universität Essen
Institut für Angewandte Thermodynamik und Klimatechnik
Universitätsstr. 15
45141 Essen, Germany

Synopsis

The traditional way to dehumidify the outdoor air in an A/C-system is by cooling the air down below the dew point temperature. For this process a refrigeration system is necessary to realise these low temperatures. Nowadays the disadvantages of refrigeration systems for dehumidification are widely known. An alternative method to dehumidify the air is by separating the process of dehumidification and cooling.

The paper will present a testing plant of 1200 m^3_{air}/h which is installed in the University of Essen. This A/C-systems works with liquid desiccants. The cooling of the process is done only by means of evaporation of water.

Measurement data of the considered A/C-plant shows that the required performance in the air condition technology could be achieved. The system represents thus an alternative to air conditioning by application of a conventional refrigeration system. Its advantage is a clear reduction of the required electrical power input in the summer and a reduced energy requirement in relation to systems which works by cooling the air below the dew point.

1 List of symbols

OA	Outdoor Air	W	Water
SA	Supply Air	A	Air
RA	Return Air	S	Solution
EA	Exhaust Air	Δx	Range of dehumidification [$g_{W.}/kg_{dry\ air}$]

2 The influence of humidity on comfort and energy consumption

The thermal comfort of a human body is mostly influenced by the heat equilibrium. The human heat transmission is done by convection, radiation and evaporation of water to the environment. The different heat transmission mechanisms take over different parts of the total heat load. The ratio is depending on various parameters. With rising air-temperature the sensible convection is decreasing meanwhile the latent heat by evaporation is increasing.

If we regarde a building climatization the persons in the building have only a small difference in radiation and convection. To be able to meet the heat balance the human body sends water to the surface to reach evaporation cooling. The related amount of water will be at 20°C between 45 g_W/h and 220 g_W/h dependent on the activity level. The relative values at 26°C are 90 g_W/h and 300 g_W/h.

This amount of water must be transferred to the air. This can be reached by a high mass transfer coefficient or by a big difference between the absolute humidity at skin level and in the room air. An increase of the mass transfer coefficient will also give an increase of the heat transfer coefficient. This correlation is given in the Lewis law. But high convective heat losses will cause the feeling of draft. To be able to avoid this a high water mass transfer must be reached with a big difference of absolute humidity. [Steimle 1997] This shows that outdoor air needs to be dehumidified which requires energy input.

In order to show the influence of outdoor humidity on the total cooling load Harriman e. al. [Harriman] proposed to calculate a „Ventilation Load Index" (VLI). The VLI describes the sensible and the latent heat load generated by one cubic meter fresh air per hour brought from the weather to space neutral conditions over the course of one year. To calculate the VLI for a given location, one must compare the outdoor temperature and humidity levels to the temperature and humidity at the set point which could be the supply air (SA) or the room air. Figure 1 shows the VLI's for a space neutral condition of t_{SA} = 20°C and x_{SA} = 9 $g_W/kg_{dry\ air}$ for selected locations in Germany. The weather data is taken from the German DIN 4710 (meteorological data) [DIN 4710] for the time between 7.00 and 18.00 o'clock.

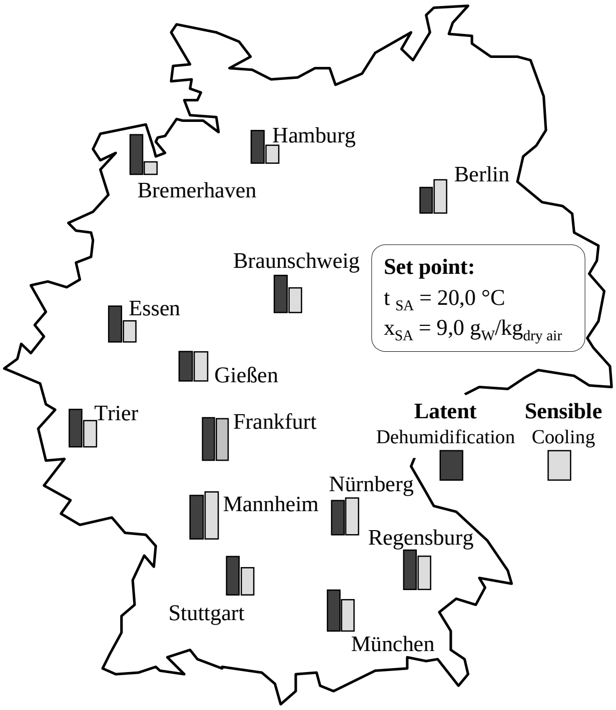

Fig. 1: Ventilation load index (VLI) for selected locations in Germany.

In most of the regions of Germany the latent VLI is higher than the sensible VLI or nearly of the same value. That means that the dehumidification process has a great importance on the total energy consumption during the air conditioning in the summer even in regions with temperate climate. For that reason the efficiency of the dehumidification process must be improved, in order to reduce the energy input.

3 Presentation of the A/C-system using liquid salt solutions

The developed A/C plant, guarantees a comfortable room air by sorptive dehumidification and cooling by evaporation of water, so that the thermodynamic functions cooling and dehumidification are separated. The system works with liquid hygroscopic material which gets into direct contact with the air in a new type of a cross-flow absorber which is integrated in a dehumidification unit. Figure 2 shows the assembly of the system.

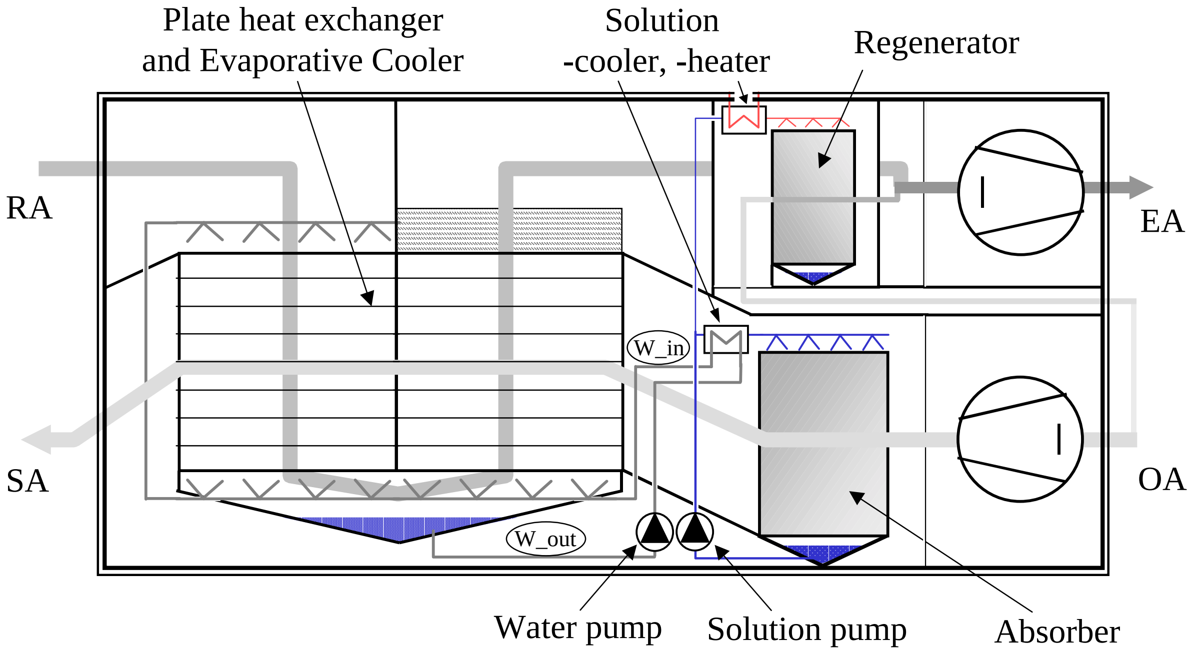

Figure 2: A/C-plant with evaporative cooling and dehumidification by absorption.

The difference in the considered sorptiv system and DEC-systems with rotary wheels is mainly the dehumidification process. Rotary wheels works with solid sorbent which becomes active on the surface layer of a dehumidification wheel. The regeneration of the sorbent is reached by heating a part of the return air which passes through the dehumidification wheel. In those systems the cooling of the supply air is realized by evaporation of water in two humidifiers installed in the ducts of the return air (indirect cooling) and the supply air (direct cooling).

In the liquid sorption system the outdoor air is dehumidified by a liquid desiccant which is cooled by circulating water from the EC-system. The advantage of a cooled absorber is a lower process temperature, so that high ranges of dehumidification can be reached.

In order to keep the process running, the weak salt solution is concentrated in a regenerator There the solution is heated and the bounded water evaporates. In contrast to systems with rotary wheels the heating of the regeneration process has no influence on the supply air status. Dehumidification and regeneration are separated from each other and do not have to be done at the same time. Using tanks to store the weak and the strong solution it is possible to regenerate when for example solar heat gains are available. In this way the storage of solar energy for climatization in form of concentrated saline solution is possible without loss.

Both the absorber and the regenerator can be bypassed if dehumidification is not necessary. The supply air fan of the new system is installed in front of the heat exchanger, so that the heat gain of the fan can be released in the heat exchanger. The use of a plate heat exchanger is advantageous. As there is a complete separation between the return air duct and the supply air duct, it is possible to oversaturate the return air in order to increase the heat transfer. This leads to satisfactory results for the evaporative cooling.

3.1 Evaporative Cooling

The evaporative cooling (EC) is realised with only one humidifier in the return air sector. The circulating water is sprayed directly in the plate heat exchanger. The plate heat exchanger used is made of double-web-plates of polypropylen. The plates are kept separated from each other by distance strips. Normally this EC-system is used in order to cool down the outdoor air. The additional use of the system for the cooling of the dehumidification process has several advantages. There is no need of an additional external cooling system, like a cooling tower. Also the use of a direct humidifier for temperature reduction is not necessary, so that hygienic problems can be avoided. The result is a clear reduction of the investment costs.

Investigations have been made in order to determine the performance of the considered EC-system. The set-point for the measurements was the standard design point for A/C-systems in Germany with an outdoor temperature of t_{OA} = 32°C and an humidity of $x_{OA} = 12\ g_W/kg_{dry\ air}$. The return air status was kept at an constant temperature of t_{RA} = 26°C with variable humidity between $x_{RA} = 8$ to $12\ g_W/kg_{dry\ air}$. The mass flow ratio of outdoor air and return air was kept constant at the value 1,0. In order to judge the E/C-system the supply-air temperature and the temperature of the circulating cooling water was from major interest. Figure 3 shows the result of the measurements.

First measurements where made without dehumidification [0 g/kg] so that the water in- and outlet-temperatures are of the same value. Increasing return air humidity leads to higher temperatures in the EC-system. The lowest temperature which can be reached is the wet bulb temperature of the return air which is also shown in figure 3.

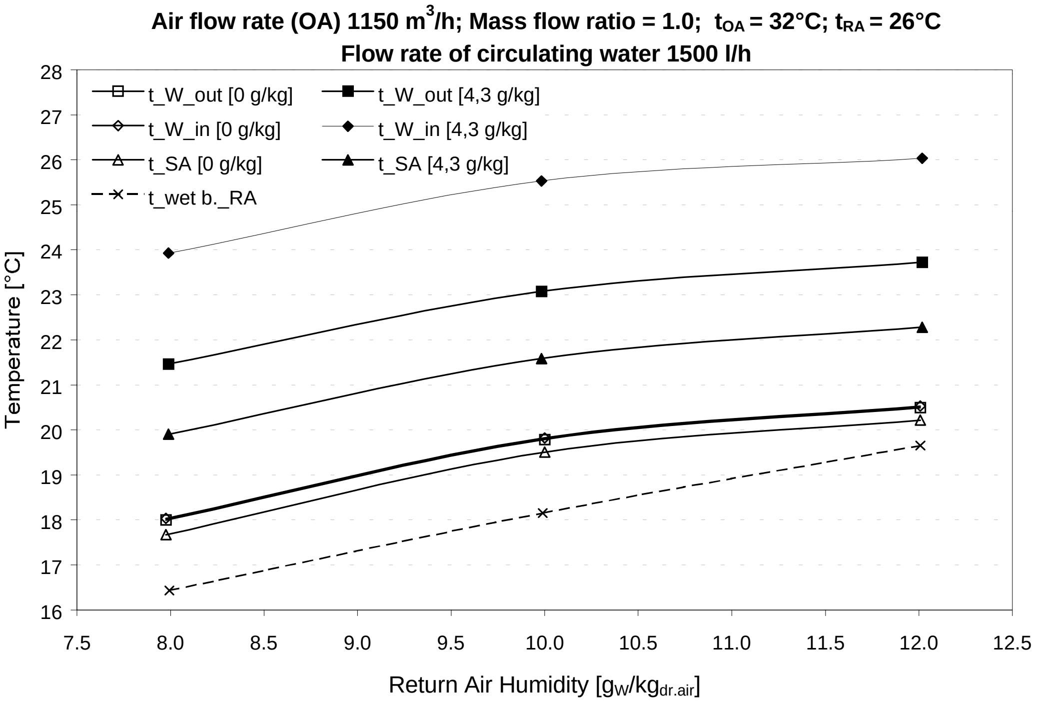

Figure 3: Achieved temperatures in the A/C-system as a function of the return air humidity

The supply-air temperatures without cooling the dehumidification-process varies between 17,7°C and 20,2°C. The values are very close to the wet bulb temperature. The heat flow from the dehumidification process leads to higher temperatures in the EC-system. The heat of an isothermal dehumidification of 4,3 $g_W/kg_{dry\ air}$ causes an increase of the supply air temperature of 2 K. The considered EC-system guarantees though a clear reduction of the outdoor temperature of max 14,3 K [0 g/kg] and 12,0 K for a dehumidification of 4,3 g_W/kg_A. An increase of the return air humidity leads to an increase of the supply air temperature. The saline solution could be kept cool with circulating water which enters the solution cooler with temperatures of 21,5°C to 23,7°C. On the basis of the water cooling the inlet temperature of the saline solution could be kept at 25°C or even lower. This temperatures lead to satisfactory results for the dehumidification as the measurement of the absorber will show.

3.2 Dehumidification with liquid salt solutions

The designed absorber is a cross-flow-type absorber. Its construction, including the liquid transport system, has to ensure a good performance in connection with a save operation of the A/C-plant. The first target was to avoid droplets in the air stream. Liquid solution droplets could cause damage in the A/C-plant in the form of corrosion and could be harmful to one's health if you breathe in aerosols of the saline solution. Several constructional details have been put in which lead to the result that no saline solution could get out of the presented cross-flow absorption system by means of the air flow.

The first detail is a practical arrangement of the liquid distribution system and the packing in connection with the air flow. Leaving the distribution system the liquid gets immediately into contact with the packing material. There it adheres because of the surface tension of the liquid and stays on the packing. To preserve that droplets could be carried out of the absorber, the end of the packing has the function of a separator. As a precaution to be on the safe side, the installation of the packing at the air outlet of the absorber is a bit longer than necessary. Furthermore the used lithium chloride solution has no volatile contents except water.

Another reason why there is no danger of liquid saline solution in the air flow behind the absorber is the developed distribution system. Moving distribution pipes guarantee an effective wetting of the packing. As the required distribution pressure is lower than 0,04 bar it is not possible to produce small droplets or aerosols. The liquid leaves the distribution tube as a laminar jet with velocities smaller then 1,5 m/s. The slow liquid jets adhere directly on the packing. The droplets on the packing are comparatively big and could not be carried away by means of the air stream. Additional the developed low pressure liquid distribution system with leads to a moderate energy consumption of the saline pump.

In the absorber we can apply all kinds of packings in order to get a great liquid surface. The packing must have a good resistance against corrosion. The selection of the packing is mostly determined by the price. Up to now we are testing several kinds of packings under the consideration of the price, and the performance. The kind of packing installed in the absorber also influences the plant operation and the control of the whole cooling- and dehumidification-system. Though a good selection of the packing material can only be done under consideration of the whole air conditioning concept.

For the investigation of the dehumidifier several measurements were carried out. Figure 4 shows the achieved ranges of dehumidification and the outlet temperatures of the air and the solution. Variable parameters have been the air velocity and the liquid load which was set at values of 1.5, 3.0 and 7.5 m_S^3/m^2h. The results are valid for the desiccant Lithium-Chloride in connection with plastic Pall®-Ring packing. All measurements were made with external cooling of the solution. The inlet temperature of the solution is constant at 25°C

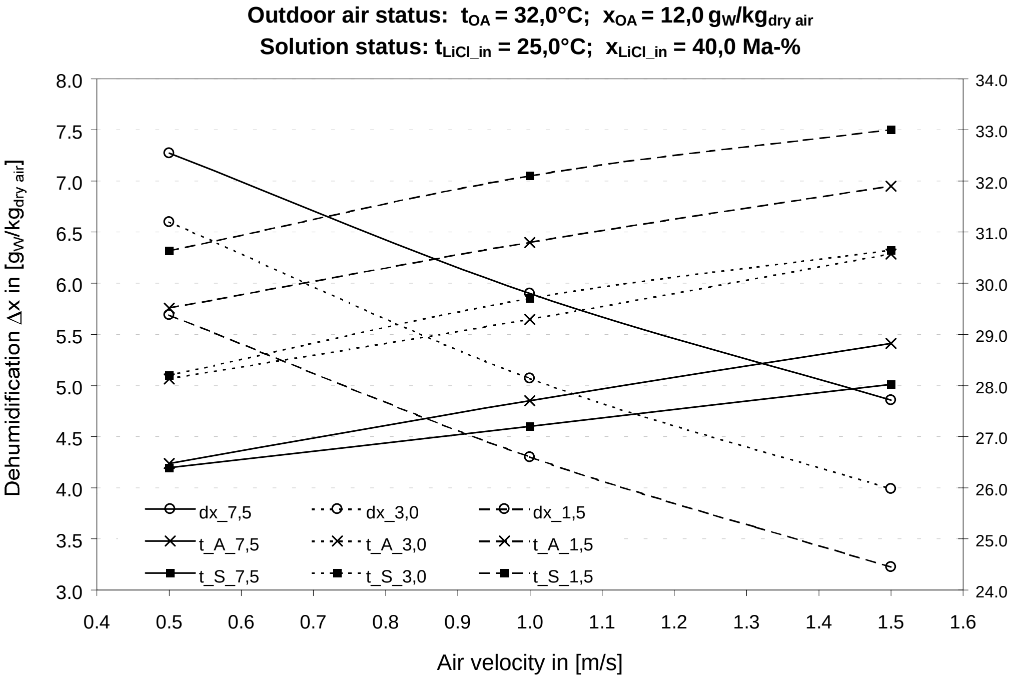

Figure 4: Achieved ranges of dehumidification Δx and outlet temperatures of the air and the solution in dependence of the air velocity and the liquid load.

The ranges of dehumidification are satisfactory for application in climatization technology. For the considered case the range of dehumidification varies between 7,3 $g_W/kg_{dry\ air}$ and 3,2 $g_W/kg_{dry\ air}$ decreasing with increasing air velocity. A liquid load of 3.0 m_S^3/m^2h makes dehumidification up to 4 $g_W/kg_{dry\ air}$ possible even when the air velocity is at 1,5 m/s. High liquid loads lead to higher dehumidification and lower temperatures in the air and the solution at the outlet. With high liquid load a good wetting of the packing is possible. This leads to an increase of the active surface for heat and mass transfer. If the liquid mass flow is higher then the air mass flow, latent and sensible heat load could be removed by the cold solution. So the changes in state of the air are isothermal or with a slight decrease of the temperature.

3.3 Regeneration

The regeneration of the weak salt solution is carried out in a separate regenerator where the solution is heated and the bounded water evaporates. The temperature needed depends on the desiccant, the atmospheric pressure, the humidity of the process air and the efficiency of the regenerator.

In dehumidification wheels the regeneration is done by heating up the storage mass with "humid" air of the E/C-process. In contrast to that the developed liquid system uses outdoor air with a lower humidity. Furthermore the saline solution is heated directly so that there is no need of a water/air heat exchanger which causes a higher energy input for the fan. The assembly of the system and the substance data of the liquid hygroscopic materials make it possible to use low temperature heat for the regeneration process. The heat losses in the exhaust air could be kept low. Figure 5 shows the sorption isothermal line of Lithium-Chloride solution at 60°C and 70°C at 1.013 bar.

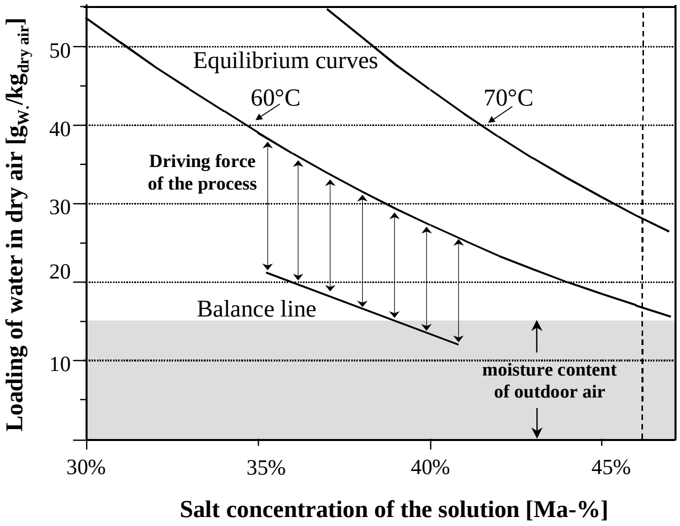

Figure 5: Operation diagram for the regeneration of LiCl-solution at 1.013 bar

Taking warm water the desorption could be done in a regenerator which is designed like an absorber. Another is possibility to use a solar collector for direct regeneration of the saline solution. It is obvious that the regeneration of the saline solution up to a concentration of 46%, which is the crystallization point of LiCl-solution at 20°C, is possible with temperatures above 60°C. The temperature can be even lower during part load operation. That shows that there are no problems to use solar heat for the regeneration.

3.4 Assembly of the A/C-system

The operation of the developed A/C-system, for an outdoor air temperature of 32°C and a humidity of 12 $g_W/kg_{dry\ air}$, is shown in figure 6.

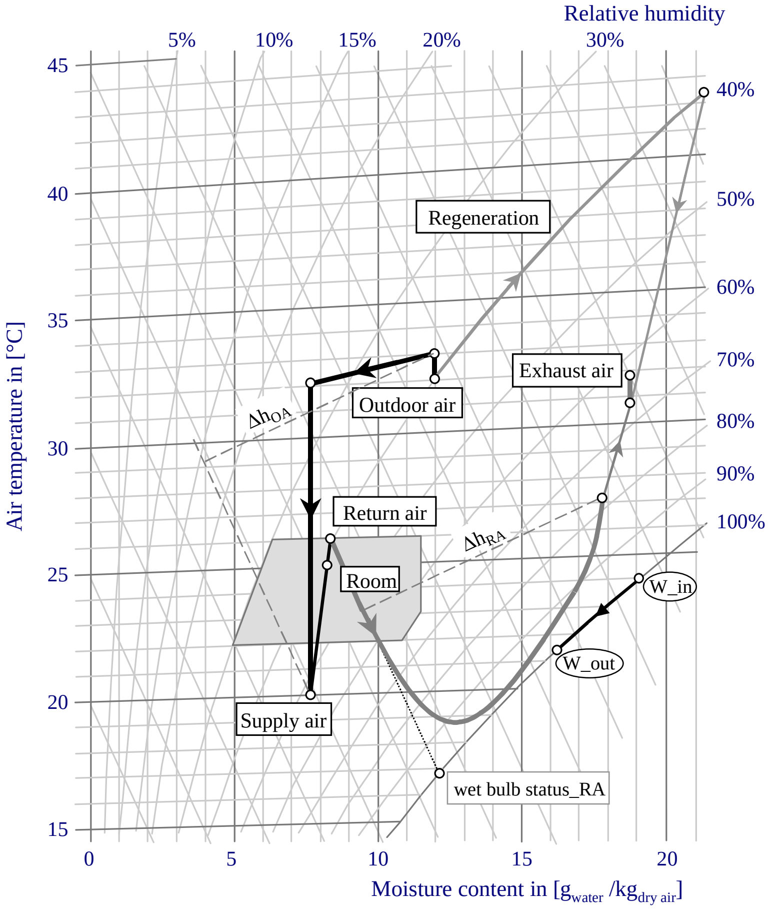

Fig. 6: Plant operation of the sorption supported A/C-system in a hygrometric chart

The supply air fan leads to an increase of the temperature of about 1 K. By cooling the solution it is possible to reach a nearly isothermal dehumidification process with a supply air humidity of 7,7 $g_W/kg_{dry\ air}$. The temperature reduction in the plate heat exchanger makes it possible to reach an supply air temperature of 20°C. Due to the sensible and the latent cooling loads the temperature and the humidity increase in the room. The grey shaded field represents the comfort zone of the German standard DIN 1946 part 2 [DIN 1946]. The heat exchange with the outdoor air and the cooling of the dehumidification process lead to an increase of the specific enthalpy of the humidified return air of about Δh_{RA} = 25,0 kJ/kg for the considered case. The values of Δh_{RA} and Δh_{OA} are exactly the same. The return air leaves the plate heat exchanger with a temperature of 27°C and a humidity of nearly 18 $g_W/kg_{dry\ air}$. If regeneration takes place, the return air and the regeneration air will be mixed and leave the A/C-plant.

4 Summary

The results show that the range of dehumidification which is needed in order to reach comfortable supply air conditions can be obtained with this new type of absorber. The presented system achieves the performance data required in the air condition technology and represent thus an alternative to air conditioning by application of a conventional refrigeration system. Its advantages are a clear reduction of the required electrical power input in the summer and a reduced energy requirement in relation to systems with a compression refrigerant cycle [Steimle 1997]. The result of economic evaluation shows that a slightly higher price of the sorptive systems can be equalized by lower energy costs. As driving power for the sorptive dehumidification process heat is needed only at lower temperature level so that for instance solar energy could be used for building climatization.

5 References:

1. Steimle, F., 1994, Feuchte als Behaglichkeitskomponente, ki Luft & Kältetechnik, Nr. 2: p.66-68
2. Harriman III, Lewis G.; Plager, Dean; Kosar, Douglas: Dehumidification and Cooling Loads From Ventilation Air, ASHRAE Journal 11/1997, pages 37-45.
3. DIN 4710. Meteorologische Daten zur Berechnung des Energieverbrauchs von heiz- und raumlufttechnischen Anlagen. Beuth Verlag GmbH Berlin. 11/1982.
4. DIN 1946 Teil 2. Raumlufttechnik; Gesundheitstechnische Anforderungen (VDI-Lüftungsregeln). Beuth Verlag GmbH Berlin. 10/1988.
5. Steimle, F., Biel, S., Röben, J., 1997: Economical comparison of comfort ventilation and air-conditioning plants, Proceedings of the 18th AIVC Conference, Athens: p. 107-115

6 Acknowledgement

The presented A/C-system is a part of a project with the title „*Entwicklung, Bau und meßtechnische Untersuchung eines sorptionsgestützten Klimagerätes unter Einsatz wässriger Salzlösungen* - Development, construction and investigation of a sorption assisted A/C-plant using liquid salt solutions". The project is made on behalf of the German research ministry (BMWi) in connection with MENERGA, Mülheim under the contract number 0329151N.