The Ninth International Conference on Construction in the 21st Century (CITC-9)
"Revolutionizing the Architecture, Engineering and Construction Industry through Leadership, Collaboration and Technology"
March 5th-7th, 2017, Dubai, United Arab Emirates

Examination of DEVap Air Conditioning Systems to Evaluate Energy Efficiency

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This research examination and study looked at the desiccant-enhanced evaporative air conditioning (DEVap) system and how this system can save energy and eliminate environmental concerns during operation of the system. Why has this system suddenly become an interesting possible alternative to the standard direct expansion air conditioning system? As with any new technology, skeptics will be forthright and bringing this into the conventional air conditioning market will create risk and obstacles to overcome

(Kozubal, et al., 2011). In order to determine how this new technology could be considered for the air conditioning market, the following general topics were assessed through three straight forward questions: (1) Will the DEVap system work in any climate situation? (2) Can the DEVap system reduce monthly energy usage/cost and lifecycle costs? (3) Will the DEVap system reduce environmental concerns? The answers to these three questions basically tell anyone considering the use of the DEVap technology the important information required to make a decision based on sound engineering documentation and principles (Woods and Kozubal, 2012).

Keywords: Energy, Climate, Environmental, Lifecycle

Introduction

Since the invention of air conditioning (AC), people have always tried to improve the AC system. The conventional AC system for the most part has been the direct expansion (DX) system. Over the years, alterations to the standard DX system have been accomplished but still no real significant changes in the DX system have really affected the overall efficiency of the system. However over the last 20 years or so, the liquid desiccant air-conditioner (LDAC) is now being considered as a legitimate alternative to the old standard (DX) system for both residential and commercial applications (Fox, McDonald & Pritchard, 2004). Recent innovations to the typical LDAC design have brought the LDAC into the realm of feasibility and use for several applications. The LDAC is fast becoming a possible competitor to the DX system in the conventional AC marketplace.

What is the importance of the LDAC and specifically the more defined desiccant-enhanced evaporative air conditioner (DEVap) becoming a challenger or mainstay in the AC marketplace? As energy prices continue to rise and become more and more a part of the everyday expenses of a residential home or commercial location, more efficient and viable AC systems are needed to lower energy consumption and overall lifecycle costs (Woods and Kozubal, 2012). Is the DEVap the system with the answers or are there other options out there to meet the ever changing needs of the AC customers.

Background

A surprising fact about the LDAC system is that it has been around for more years than one expects since this particular process has been used for industrial and agricultural purposes and specifically used for humidity control in textile mills and post-harvest low temperature crop drying harvest in-stores (AIL Research, 2002). These systems were and still are vital to the productivity and profitability of both the textile and agricultural industries (AIL Research, 2002). Humidity control or dehumidification is one of the most important components of the LDAC system. The LDAC system must control the humidity to levels that allow proper functionality of the system equipment and components.

Hence, the development more recently of the DEVap system since its primary function is a more scientifically advanced humidity control or dehumidification process (Kabeel and Almagar, 2013).

The specific DEVap technology has only been around for the last 7 plus years and each year seems to bring more and more developments that lead the industry to believe that this system can function as designed and offer a viable alternative to the old industry standards for air conditioning systems (Katejanekarn, 2010). Currently, only laboratory development and testing of this system exists and no real installations of the system have been accomplished to date. The laboratory development has been created by the National Renewable Energy Laboratory (NREL) of the US Department of Energy (DOE) (Kozubal, et al., 2011). Testing and simulations of the system are on-going and a real working prototype model of this system is expected to be completed in the spring of 2014 (Kozubal, et al., 2011). The developers and simulators who have been working hand in hand feel confident the working prototype model will finally be the breakthrough to allow the DEVap system to be a complete and legitimate competitor in the AC marketplace. The simulations and testing will be discussed further in this paper.

Purpose

The purpose of this research was to investigate the claims and statements provided by the developers and laboratory testers as to the validity that the DEVap system technology will lower energy usage costs and the overall life cycle costs of an AC system. More precisely, will the DEVap system actually reduce the monthly energy usage and reduce the energy costs for the life of the DEVap system versus the same costs for a traditional DX system? The resolutions to the following questions could solidify the validity of the DEVap system:

- Will the DEVap system work in any climate situation?
- Can the DEVap system reduce monthly energy usage/cost and lifecycle costs?
- Will the DEVap system reduce environmental concerns?

Background

The DEVap system is similar to previous desiccant systems but the main difference is it use of highly concentrated aqueous salt solutions of lithium chloride or calcium chloride for cooling outdoor air (Woods and Kozubal, 2013). Supposedly the use of either chloride will allow better humidity control than earlier desiccant cooling systems. The better humidity control is achieved through the use of a DEVap cooling core (see figure 1). It should also be noted that no refrigerants are required for the DEVap system thus greatly reducing harmful emissions to the atmosphere.

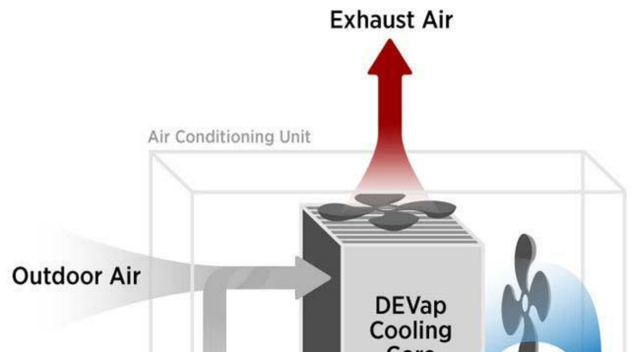


Figure 1 – Typical DEVap Cooling Core

Further explanation of the DEVap core process indicates that the following occurs when the process enhances the typical LDAC (see figure 2):

> Ventilation air [1] and warm air [2] are mixed into ma single air stream. This mixed air stream (now the product air) is drawn through the top channel in the heat exchange pair. The product air stream is brought into immediate contact with the drying potential of the liquid desiccant [d] through a vapor-permeable membrane. Dehumidification [ii] occurs as the desiccant absorbs water vapor form the product air. The product air stream is cooled and dehumidified, then supplied to the building space [3]. A portion of the product air, which has had its dew point reduced (dehumidified), is drawn through the bottom channel of the heat exchange pair and acts as a secondary air stream. The secondary air stream is brought into immediate contact with the water layer [c] through a vapor-permeable membrane [b]. The two air streams are structurally separated by thin plastic sheets [a] through which thermal energy flows, including the heat of absorption [i]. Water evaporates through the membranes and is transferred to the air stream [iii]. The secondary air stream is exhausted [4] to the outside as hot humid air (Kozubal, et al., 2011).

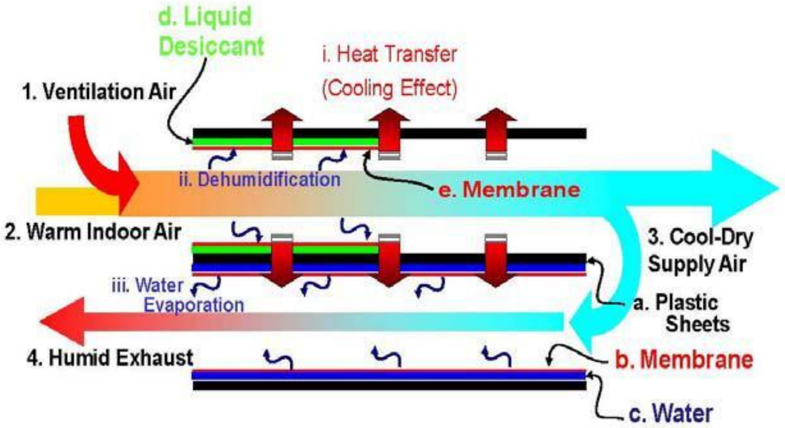


Figure 2 – Physical DEVap Concept Description

As stated earlier, the NREL has been the exceptional leader in the development and testing of the DEVap system. The NREL has been using building energy models to simulate the DEVap system to determine the effectiveness of the system and how it relates to energy usage and life cycle conditions (Kozubal, et al., 2011). The paper will closely exam the simulation data as well as some typical design systems that have been developed by the NREL in conjunction and cooperation with AIL Research and Synapse Product Development through public grants and private industry donations (AIL Research, 2002).

Research Examination

The NREL was tasked to perform simulations of the DEVap system technology in various climatic situations that could anticipate most of the scenarios for applications within the United States and other areas of similar climates. The simulations were performed utilizing building energy models (discussed earlier) to extract data and analysis for the performance of the DEVap system. The NREL determined that the most useful simulations would be to simulate new and retrofit AC systems for residential applications and new and retrofit AC systems for commercial applications. These simulations will basically involve enough situations to produce useful and informative data to allow a thorough and comprehensive investigation of the DEVap system.

In a typical residential configuration, a 3 ton DEVap system can be comprised of a DEVap AC unit, a two stage regenerator, and desiccant storage (see figure 3). The regenerator can be powered by using natural gas or thermal heat and the DEVap core can be integrated with a furnace and air handler if present. The regenerator contains a 30 kBtu boiler (typical DHW's are 200 kBtu) and a HMX scavenging regenerator (Kozubal, et al., 2011). In theory, this type of DEVap set up will perform the air conditioning with independent temperature and humidity control, provide a dedicated dehumidifier and include a mechanical ventilator. The DEVap residential application will supply air at 380 or less cfm/ton.

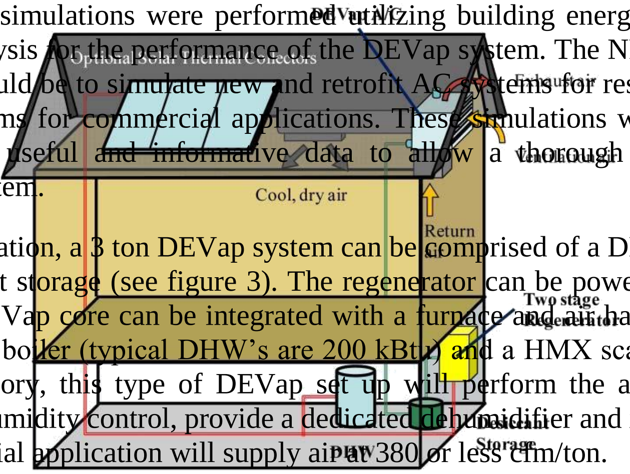


Figure 3 – Typical DEVap Residential Configuration with Solar Option

In a typical commercial configuration, a DEVap roof top unit (RTU) system can be comprised of a DEVap AC core, a two stage regenerator, and desiccant storage (see figure 4). This type of unit is expected to have a larger core than a typical DX evaporator coil but the regenerator is very compact and no DX condensing section is necessary. Overall the DEVap RTU will be smaller than a comparable DX RTU. The DEVap RTU will also integrate with a building similar to the standard DX RTU and no significant changes will be necessary for the installation and ducting process. It should also be noted that the commercial application for the regenerator can be powered by using natural gas and in some cases thermal heat. As with the residential unit, the DEVap RTU commercial application will supply air at 380 or less cfm/ton.

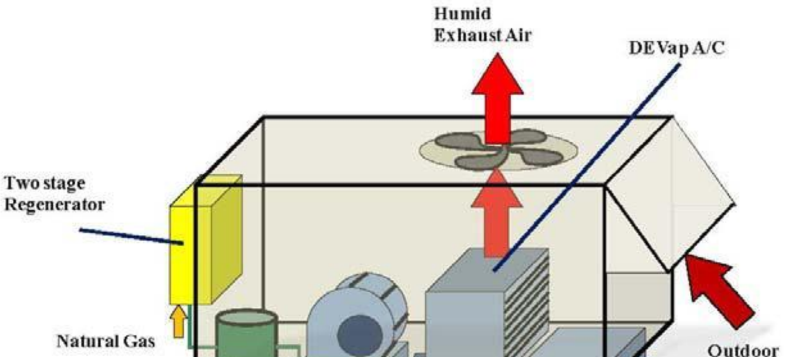


Figure 4 – Typical Packaged DEVap RTU

Data Examination

Eight City Simulations

In order to provide useful data through the simulations, the comparison between the DEVap and DX systems had to be similar in size and the parameters had to be as close to identical as possible. The NREL used the Transient Systems Simulations (TRNSYS) program for a building energy model to simulate the parameters for each system (AIL Research, 2002). Four simulations were performed for each of the eight cities representing a typical sample of the various climates across the U.S. (see table 1). The sizes of the systems were in 1 ton increments in order to meet the 100% sensible load.

Table 1 – AC System Capacity in Each City Simulated

	Phoenix	San Francisco	Washington, DC	Tampa	Atlanta	Chicago	Boston	Houston
New construction								
DX	4 ton	3 ton	3 ton	3 ton	3 ton	3 ton	3 ton	3 ton
DEVap	4 ton	3 ton	3 ton	3 ton	3 ton	3 ton	3 ton	3 ton
Retrofit								
DX	4 ton	3 ton	3 ton	3 ton	4 ton	3 ton	3 ton	4 ton
DEVap	4 ton	3 ton	3 ton	4 ton	4 ton	3 ton	3 ton	4 ton

The DX system consisted of a seasonal energy efficiency ratio (SEER) -13 air conditioner with a stand-alone dehumidifier, except for city of Phoenix. The DEVap system consisted of a two stage regenerator operating with a coefficient of performance (COP) of 1.2 and variable speed supply and exhaust fans with 50% efficiency. Since the simulations not only examined performance, costs and life cycle costs were also considered for a full comparison of the two systems (ASHRAE. 2006).

Cost Analysis Simulations

As is the case with most cost comparisons, assumptions had to be made to validate a legitimate analysis. In order to perform a full cost comparison, the annualized cost of cooling in dollars per year had to be determined. (see table 2). The assumptions were based on available date for past performances of DX systems and how they relate to energy consumption (ASHRAE. 2006).

Table 2 – Economic Analysis Assumptions.

Assumptions	New Construction	Retrofit
Market discount rate	0.08	0.08
Loan rate	0.05	0.07
Inflation rate	0.02	0.02
Analysis period	15	15
Loan period	30	5
Effective income tax rate	0.3	
Property tax rate	0.02	
Ratio of down payment to initial investment	0.1	
Ratio of assessed value to installed cost	0.7	

The life cycle costs are used along with the present worth factor to determine an annualized cost of cooling. Each system has an expected life that is used in the cost analysis so as to provide an accurate cost comparison. After all the simulation data was gathered and confirmed it was time to perform the actual simulations for the DEVap and DX systems comparisons. Again to reiterate, the simulations were run to determine energy efficiency, systems performance and systems costs.

Simulation Results

The simulations were performed by the NREL with the stated conditions for each of the eight chosen cites. The first data analysis reveals that cities with a higher daily humidity (Houston, Atlanta) can cause an issue with the DEVap system. Both the DEVap system and DX system were calibrated to meet the indoor temperature set point and maintain a temperature below 78 degrees for 100 percent of the hours. However, the DEVap system was designed to lower humidity in a space to a lower relative humidity during peak cooling season. This is possible because the DEVap system has the ability to achieve a lower sensible heat ratio at peak (Jain, Tripathi & Das, 2011). The data from the city of Houston during the peak season indicates the relative humidity is lower in the DEVap system versus the DX system (see figure 5).

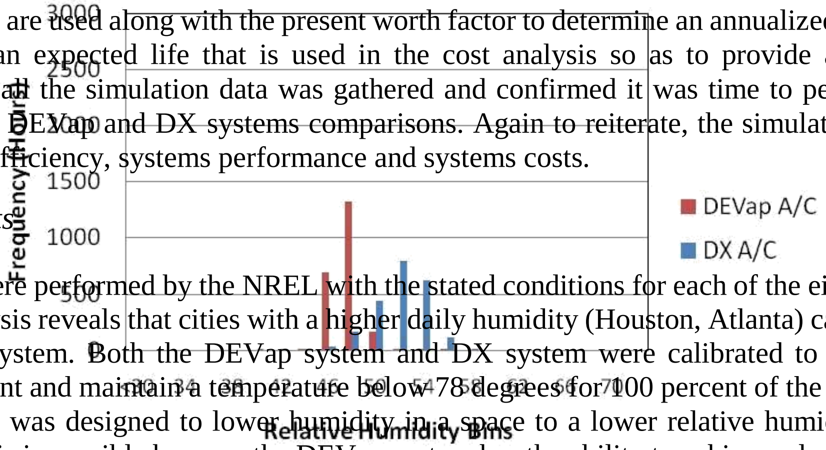
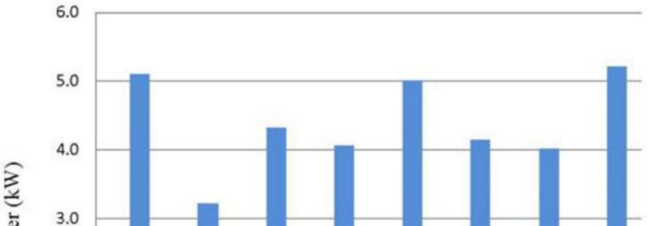


Figure 5 – Indoor Relative Humidity Histograms for Houston in June-August

This lower humidity causes the DEVap system to use more energy than necessary so it’s obvious that further optimization of the DEVap control strategy will be needed in order to reduce energy usage and eliminate air that is too dry (low humidity). Optimum indoor relative humidity for AC systems is considered to be around 55%.

Another data result is examining the power usage during peak power hours. Peak power is considered the time of most energy usage so obviously this analysis is the most important factor in overall power usage. A review of the data reveals a very significant difference is usage (see figure 6).



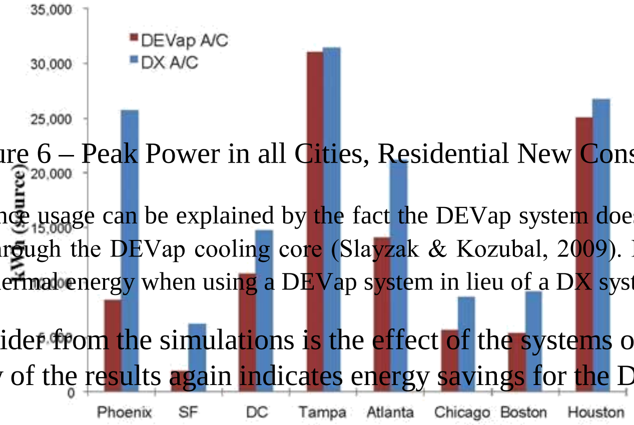


Figure 6 – Peak Power in all Cities, Residential New Construction

The significant power difference usage can be explained by the fact the DEVap system does requires a compressor and only fan power to push air through the DEVap cooling core (Slayzak & Kozubal, 2009). Most of the AC's energy is switched from electricity to thermal energy when using a DEVap system in lieu of a DX system.

A third data result to consider from the simulations is the effect of the systems on source energy (power, water, gas, etc.). A review of the results again indicates energy savings for the DEVap system versus the DX system (see figure 7).

Figure 7 – Source Energy in all Cites, Residential Retrofit

These results again solidify how the humidity control can affect the source energy usage. The difference in energy usage is noticeable different for Phoenix (very dry climate) versus Houston (very humid climate). This again magnifies that the DEVap system requires additional optimization of the DEVap control strategy to reduce energy usage and control humidity for better comfort (Jain, Tripathi & Das, 2011).

Finally the life cycle costs (LCC) of each system must be considered for data analysis. After compiling the data, the costs reveal that upfront costs are higher for the DEVap system but these costs are quickly offset by energy usage (see figure 8).

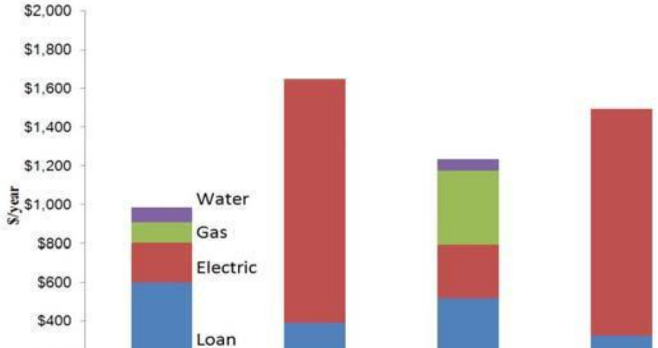


Figure 8 – LCC's for Phoenix and Houston, Residential New Construction

It's interesting to note the different energy usage for the dry climate versus the humid climate. The simulations again reveal the need for humidity control and how the optimization of the controls for the DEVap system is necessary in order to obtain optimum performance and produce comfortable indoor humidity to meet typical industry standards.

Conclusion

At the outset of this paper, the questions were asked about how the DEVap AC system compares to the standard DX AC system. Through the research and examination of previous studies done for the DEVap system, it appears that the DEVap system can be a technology breakthrough for the AC industry. The estimates of energy savings as demonstrated through simulations only enhance and support the claims of the DEVap system by its developers. The first question posed by this paper asked could the DEVap system work in any climate. The research and simulation data suggests that the DEVap system can work in any climate situation.

The simulation results shows that the DEVap system works in dry climates with little or no modifications required to the typical DEVap design for both residential and commercial applications. However, more humid climates will require redesign or alteration of the control system so humidity can be optimized to a comfortable level and energy usage reduced even more than currently expected.

The second question posed by this paper asked will the DEVap system reduce monthly energy costs and life cycle costs. The analysis indicates that monthly energy costs will be significantly reduced in area of dry climates and even reduced in areas of humid climates. The energy usage in areas of humid climates can be reduced by the modifications stated above. Lifecycle costs through the simulations details that over the system lifetime the DEVap system will outperform the DX system even though upfront costs for the DEVap system are higher than the DX system. The third question passed by this paper asked can the DEVap system reduce environmental concerns. Since the DEVap system contains no refrigerant and only uses aqueous solutions of chloride, the release of harmful gasses into the atmosphere has been completely eliminated. The DEVap system is environmental friendly.

Finally, the DEVap system is still in its infancy in regards to being a viable product for the AC industry. However, the simulation data and costs analysis numbers are very positive and foresee a product that could dramatically change the AC industry. Once the working prototype is up and running in the spring of 2014, more valuable and informative data will be available to better determine if the DEVap system is the wave of the future for the AC industry.

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