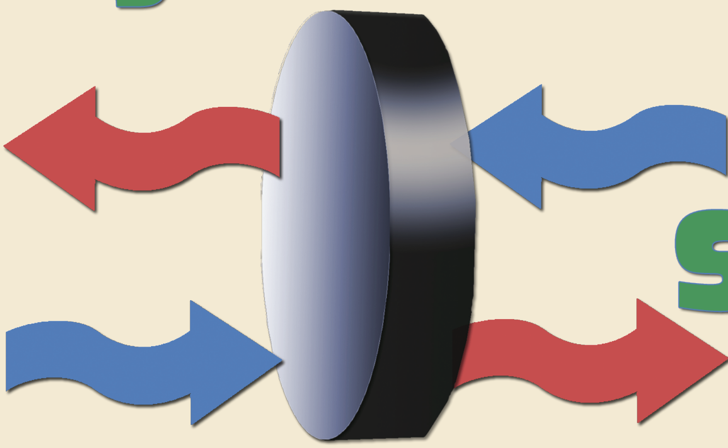
Hybrid Desiccant Cooling Systems



By M.H. Saidi and **S. Vazirifard**

HVAC systems that use heat-regenerated desiccant wheels to remove moisture can be energy-efficient alternatives to traditional systems. Site-specific conditions and differing application requirements must be understood and quantified before desiccant-assisted hybrid systems can be justified on economic grounds. Although a detailed analysis is generally required, a few key variables drive costs and benefits. When two or more of these key variables favor a hybrid system over a conventional system, then a detailed analysis of the benefits vs. costs of a hybrid desiccant system is appropriate.

A study of these key variables was performed for different building types in several cities in Iran. The results demonstrate that hybrid systems have the potential to compete economically with conventional HVAC systems in Iran.

Iran has complex climatic conditions, ranging from subtropical to subpolar. In the summer, temperatures vary from as high as 129.2°F (54°C) to as low as 33.8°F (1°C) across the country. Summer design conditions of various cities are shown in *Figure 1*.[1] For example, the city of Masjed-soleiman, located in one of the southwest provinces of the country, has a hot and dry design point of 118°F (48°C) and 0.0081 lb/lb (8.1 g/kg). In contrast, the city of Kangan, located in a southern province, has an extraordinarily humid design point of 110.5°F (43.6°C) and 0.0304 lb/lb (30.4 g/kg). This represents about 14% more moisture than the peak dew-point design point for Tampa, Fla., on the Gulf Coast of the U.S., and 16% more moisture than the peak dew-point design for the Mediterrenean island of Mallorca, Spain.

As shown by Kasmaiee,[2] evaporative coolers cannot be used in some regions in the summer because of the high humidity content of the air. These regions usually use air conditioners and packaged units that use conventional vapor compression cooling system. Unfortunately, some difficulties with their use occur, including high electricity consumption for dehumidifying the air. The air must be cooled much more than is needed for sensible cooling to satisfy the needed latent cooling.

In the last decade, desiccant dehumidification technology is becoming an alternative or supplement to conventional vapor compression systems for cooling and air conditioning in commercial and educational buildings. Desiccant-based systems can be cost-effective because they use low-grade thermal sources to remove moisture from the air. In fact, they substitute some

About the Authors

M.H. Saidi is associate professor of mechanical engineering at Sharif University of Technology, Center of Excellence in Energy Conversion, Tehran, Iran. **S. Vazirifard** is at the Tara Tarh Engineering and Technological Company, Tehran.

of the electrical energy needed by some type of low-grade energy such as heat from gas heaters or boilers, solar energy, heat reclaim coils, hot water or excess steam capacity during the summer.

A typical hybrid system combines a desiccant system with a conventional vapor compression cooling system as shown in *Figure 2*.[3] Beside using less electrical energy, other benefits include reduction in the size of the conventional system, capability of independent control of temperature and humidity, possibility of reducing moisture content of the air below the 40°F (4°C) dew-point temperature and improving the indoor air quality because of precise humidity control.

Hybrid Desiccant Cooling Systems

The vapor compression cycle is used in conventional cooling packages to provide proper air for different places. *Figure 3* shows the process of air in this system. The goal of the process in this figure is to go from Point A to Point D, in which air passes through a cooling coil and is cooled sensibly. This means that it does not lose any moisture, and only its dry-bulb temperature is lowered.

To lower its moisture content, it must be cooled to a lower temperature to get the air to the saturation line. From that point, it begins to lose moisture. To arrive at this point, manufacturers typically use more rows of cooling coils, so that the last rows will handle the latent cooling. However, often this causes air to be cooled more than needed, so a reheat coil is used, which often uses electricity. This extra step requires extra energy. *Figure* 3 shows the problem arises from the attempt to reduce latent load. To avoid this extra energy use, desiccants can be used to remove the latent portion of the load (the moisture load).

Hybrid desiccant systems are those systems that use desiccants with conventional vapor compression cycles. *Figure 2* shows one common system type uses vapor compression to remove the sensible load, and a heat-regenerated desiccant wheel to remove the latent load, using both technologies at their point of maximum efficiency. As shown in the literature, when using hybrid desiccant cooling systems, the energy use is lowered. In some situations, it has shorter periods of payback, which make using the systems feasible.[4–6]

Conditions Favoring Hybrid Desiccant Cooling Systems

Before the application of desiccant-based hybrid systems in a building can be justified on an economic basis, specific conditions of the site and different applications' requirements must be understood.

These key variables are as follows:[3]

- Allowable maximum humidity level in the conditioned space (above 50°F [10°C] dew point, the buildings are less favored);
- High latent load fraction (above 25%);
- High fresh air ventilation requirement;
- Availability of exhaust (return) air for low-cost post-cooling of the desiccant-dried air
- High electrical demand and high costs per kWh;
- Availability of cheap/free reactivation energy source; and
- A value to high indoor air quality.

Quantifying these key variables shows a general view of the practicality of desiccant-based systems in any location.

Evaluating the Key Variables in Iran

To find the potential of using hybrid desiccant cooling systems in Iran, an evaluation of the key variables was done for different parts of the country. The potential is related to two major parameters: the building type and local climate design conditions.

Level of Indoor Humidity

The level of allowable indoor humidity is governed by the building type and its use. In most commercial building applications, deep drying (dew point <40°F [4°C]) is rare, although this dew point is necessary for special places such as storage rooms and \ some industrial applications. The recommended level of indoor dew point for a typical office building is between 51°F and 57°F (11°C and 14°C), while the level for libraries and museums is between 46°F and 54°F (8°C and 12°C).

High Latent Load Fraction (>25%)

To find the buildings in which their latent load fraction is more than 25% of the total load, an overall load estimate is required.

A cooling load calculation consists of sensible and latent (moisture) components. The sensible component consists of heat gain through structural components such as walls, floors, ceilings, etc.; windows; as well as the sensible load caused by infiltration and ventilation, occupancy, lighting and equipment. The latent portion of the cooling load is evaluated separately. Its principal components are the high and constant loads from infiltration and ventilation from outdoor air. Additionally, smaller and intermittent latent loads occur from occupants and from miscellaneous sources such as cooking, laundry, and bathing. These miscellaneous latent loads are sometimes covered by the outdoor air component, because most of the equipment that could be sources of latent load have exhaust fans that vent most of the moisture from these sources.

Considering only the outside air load, two major conditions exist. When the latent fraction of total load is below 25%, the sum of this load with other loads that were considered before will constitute a sensible heat ratio of above 75%

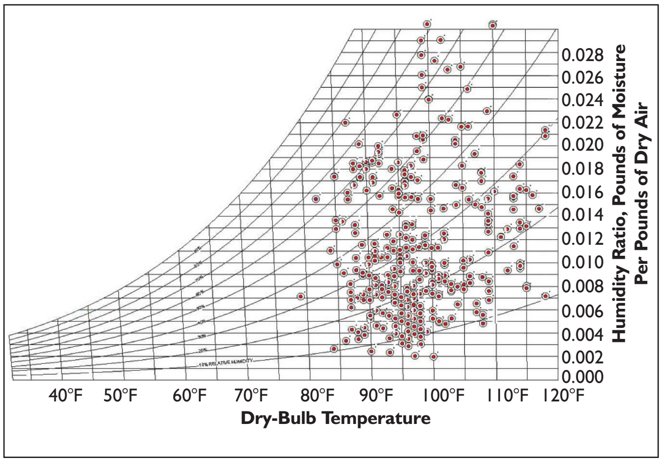


Figure 1: Summer design conditions of some Iranian cities.

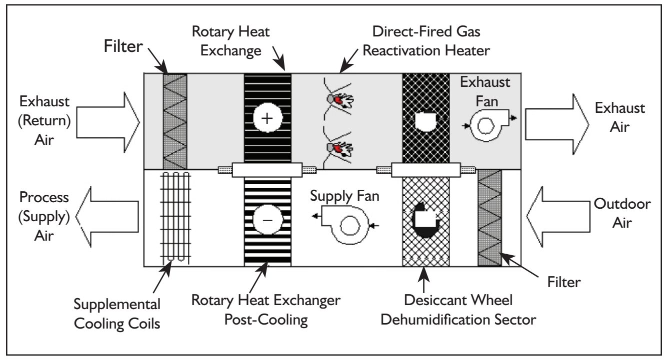


Figure 2: A typical hybrid system.[3]

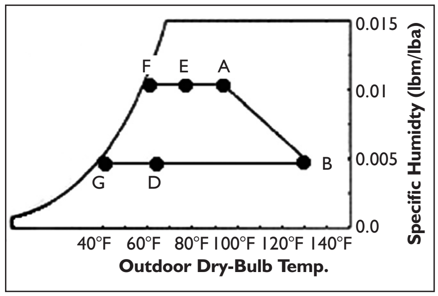


Figure 3: Process of air in psychrometric chart.

(latent load ratio of below 25%), and it would not satisfy the above key variable. However, when it is above 25%, the sum of two parts of load may or may not cause latent load fractions of above 25%.

Since calculating total load of a building depends on a lot of parameters, a graph was made to relate it only to the load of air. In *Figure 1* the following equation is used.:

$$x \times a + (1 - x) \times b \geq 25\% \quad (1)$$

In *Figure 4*, applying Equation 1, the minimum latent load needed in relation to the total load for air load has been shown based on two different parameters. One is the ratio of air load to total load in the abscissa, which is shown by x in the Equation 1, and the other is specific latent load ratio of other loads. That means loads other than the air load shown in the right side of *Figure 4* and designated by b in Equation 1.

As the density of people and/or appliances increase, the latent load increases, and lines shift more to right and down, requiring fresh air increases as well. Also, the people and appliances produce more latent heat, so the minimum latent load ratio needed in air load decreases.

The result is, in the regions that air will have a fraction of about 25% to 50% latent load, only specific buildings will satisfy the key variable of high latent load fraction. These buildings include those with high density of latent load sources that need high percentage of fresh air as well. Furthermore, in regions with more than 50% latent load of air, more buildings will satisfy the previous key variable. But, in the region where air latent load ratio is below 25%, there may be only a few exceptions that may satisfy the previous key variable and can be ignored in this consideration.

As a result, considering the latent load fraction of air load can be used to find the proper zone, including buildings with high latent load fraction.

To determine load of outdoor air we have:[8]

$$H_s = 1.1 \times \text{cfm} \times \Delta T \quad (2)$$

$$H_L = 0.68 \times 7{,}000 \times \text{cfm} \times \Delta W_{LB} \quad (3)$$

As approximate equations for determining sensible and latent loads, Equations 2 and 3 can be used. Dividing the second by the first:

$$\frac{H_L}{H_S} = \frac{0.68 \times 7{,}000}{1.1} \times \frac{\Delta W_{LB}}{\Delta T} \quad (4)$$

To have the latent load fraction of above 25% $\left(\frac{H_L}{H_S + H_L} > 0.25\right)$ in fresh air load means $\frac{H_L}{H_S} > \frac{1}{3}$ there will be:

$$\frac{0.68 \times 7{,}000}{1.1} \times \frac{\Delta W_{LB}}{\Delta T} > \frac{1}{3} \Rightarrow \frac{\Delta W_{LB}}{\Delta T} > 7.7 \times 10^{-5} \quad (5)$$

Choosing the comfort point in the psychrometric chart and

Nomenclature

H_S: Sensible heat (Btu/h)
CFM: Airflow rate
ΔT: Temperature difference (°F)
H_L: Latent heat (Btu/h)
ΔW_{LB}: Humidity ratio difference (lb H_2O/lb DA)
x: Share of air load in total load
a: Share of latent air load in total air load
b: Share of latent load of other loads (except air load) to total load

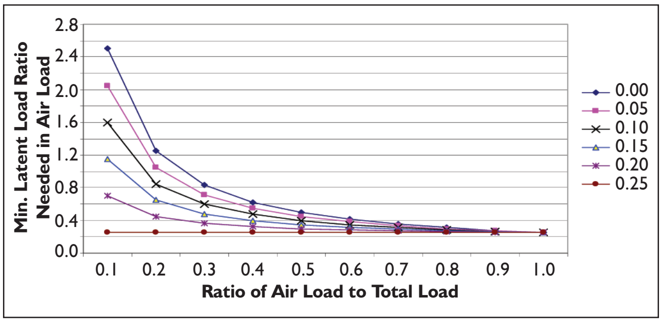


Figure 4: Minimum latent load ratio needed in air load for specific latent load ratio in other loads.

drawing a line with the above slope in right-hand side of the point, the upper zone of the line would be the zone we are seeking.

As discussed in the last part, to find the proper zones, the line of 50% latent load in fresh air load must be found. To find the proper zone for the above variable, the slope of the dividing line has been found in the same way as previously done for the line of 25%. The slopes are:

To have more than 50% latent load in fresh air load:

$$\frac{0.68 \times 7{,}000}{1.1} \times \frac{\Delta W_{LB}}{\Delta T} > 1 \Rightarrow \frac{\Delta W_{LB}}{\Delta T} > 2.3 \times 10^{-4} \quad (6)$$

Specifying these lines, the psychrometric chart has been divided into three different zones as shown in *Figure 5* and as specified below:

Zone 1: Regions that most of the buildings even with lower internal latent loads have total latent load fractions of above 25%;

Zone 2: Regions in which only buildings with high internal latent load fractions will have more than 25% latent load fraction of the total load; and

Zone 3: Regions in which buildings rarely can be found with latent load fractions of more than 25%, and can be estimated as non-satisfying region.

By compiling the psychrometric of *Figure 5* with *Figure 1*, the regions of Iran that satisfy the key variable of high latent load fraction are chosen (*Figure 6*).

Fresh Air Intake

The percentage of fresh air to total supply air basically depends on building type. As a general rule, in buildings where the density of people is high, more fresh air must be used. Also, in places where more contaminants are in the room, such as smoking areas or appliance areas, the need for fresh air increases. Some commercial buildings (schools, hospitals, restaurants, and retail establishments) require considerable fresh air intake (greater than 20%).[10] Furthermore, one typical building that needs significant fresh air are mosques, where during prayer times, a significant number of people are present, and each one needs at least a minimum quantity of 15 cfm fresh air.[10]

Availability of Exhaust (Return) Air for Post-Cooling

Due to the high temperature of air that has passed over the desiccant, exhaust (return) air still may be used to cool the supply

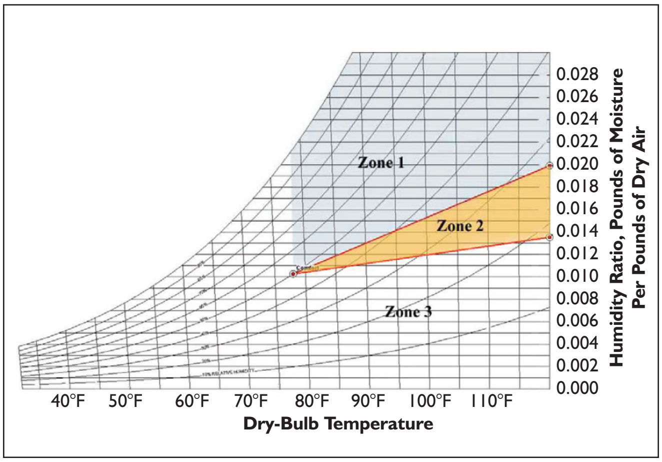


Figure 5: Different zones for latent load fraction of exchange air.

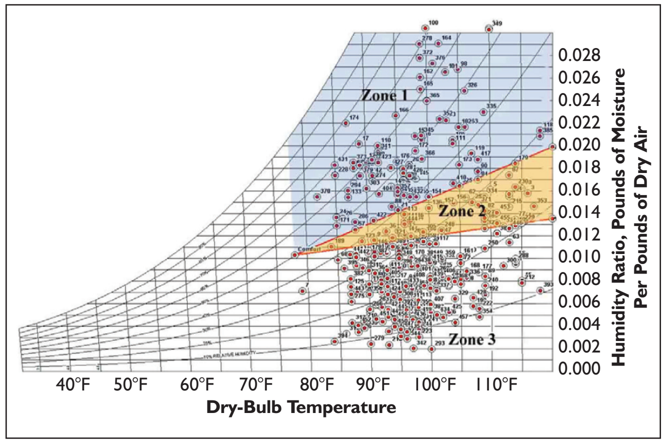


Figure 6: Cities in Zones 1, 2 and 3.

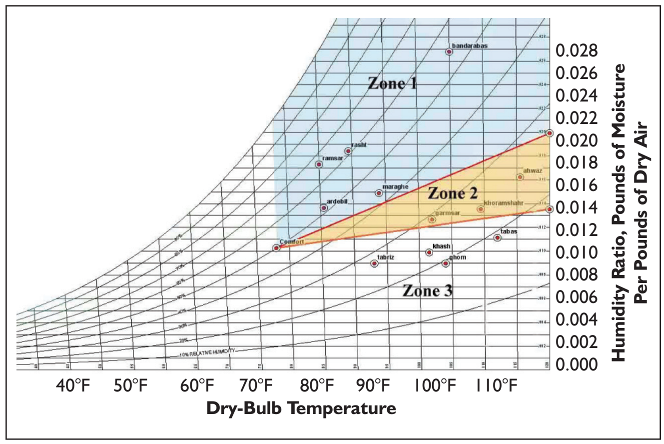


Figure 7: Selected cities of three zones.

air and so recover a part of sensible cooling energy needed. In the previously mentioned buildings where fresh air requirements are high (greater than 20%), desiccant-based systems using a combination of fresh and exhaust air can be more cost-effective than others. Although in some buildings such as those with large smoking areas, using exhaust air may not be easy due to the high contaminant content of the air, and so the exhaust air cannot be used for sensible heat recovery. In fact, this situation occurs for some of the buildings that have high fresh air ratios.

Demand and Energy Costs

In Iran, as with countries that have hot summers in most areas, a high demand exists for electricity in summer. The summer electricity tariff is about 20% more than rest of the year in Iran.[11] Also, the demand for gas use is low in this season.

Oil and natural gas are the major sources of primary energy in Iran. Unlike countries where only a small part of electrical energy is natural gas fired (18% for the U.S), about three-quarters or more of the electric power is natural gas fired in Iran. The known reserves of Iran are about 1.25 quadrillion ft^3 (35.4 trillion m^3), which account for 16% of the world's total known resources.[12] When converting natural gas energy to electrical energy, a high portion of it is lost, so substituting some electrical energy with natural gas can make a big difference in Iran.

The prices of natural gas and electrical energy in Iran are much lower than countries such as the U.S. For example, the price of 35 ft^3 (1 m^3) of natural gas has been $0.015 in Iran[13] but about $0.35 in the U.S.[14] That is about 23 times lower for Iran. Also, one kWh of electrical energy price has been $0.924 in the U.S.[15] However, it is $0.163 in Iran,[16] which is about 5.6 times lower in Iran. Although both prices are lower in Iran, natural gas prices are much less than electrical energy prices.

Availability of Cheap/Free Reactivation Energy Source

This variable depends on the real conditions of the working of the building's system. If there is a source of cheap or free energy, such as waste heat of condensers, engines, or gas turbines, it can be used to regenerate the desiccants at low cost. Also, sometimes necessary heat sources can be used for the rest of the year for other purposes such as boilers. It can be estimated that a system of heating used during the cold season also can be used for providing cheap reactivation energy and satisfy the related key variable. Kasmaiee [2] has shown that a region mostly in south of Iran, located at the north of Persian Gulf and Oman Sea, does not need heating during the cold season. The heating appliances typically used in the winter are used for cooling.

Indoor Air Quality

Indoor air quality is difficult to quantify in terms of economic benefit, but is essential for many buildings (e.g., hospitals and nursing homes). Desiccant-based systems improve indoor air quality because they precisely control moisture levels. Where conventional systems are used in humid climates, there is potential for microbiological growth in the ducts and condensate drain pans because of inadequate moisture removal. This is not a problem for a desiccant-based system because there is typically little water on a post-desiccant cooling coil or, subsequently, in the drain pan and the air-distribution ducts. As a result, special buildings that need a specific level of indoor humidity, such as hotels and hospitals, satisfy the key variable of indoor air quality.

No.	City	Dry-Bulb Temp.	Humidity Ratio	Total Coil Load	Sensible Coil Load	LHR
1	Bandarabas	105.0°F	0.02677 lb/lb	28.1 tons	14.4 tons	48.75%
2	Rasht	89.5°F	0.01841 lb/lb	19.1 tons	11.0 tons	42.41%
3	Ramsar	85.0°F	0.01730 lb/lb	17.4 tons	10.1 tons	41.95%
4	Ahwaz	115.5°F	0.01623 lb/lb	22.9 tons	16.0 tons	30.13%
5	Ardebil	85.5°F	0.01364 lb/lb	13.1 tons	9.2 tons	29.77%
6	Maraghe	94.0°F	0.01489 lb/lb	15.5 tons	10.9 tons	29.68%
7	Khoramshahr	109.5°F	0.01355 lb/lb	20.4 tons	15.1 tons	25.98%
8	Garmsar	102.0°F	0.01267 lb/lb	16.7 tons	12.7 tons	23.95%
9	Tabas	112.0°F	0.01113 lb/lb	18.6 tons	15.3 tons	17.74%
10	Khash	101.5°F	0.00990 lb/lb	14.3 tons	12.3 tons	13.99%
11	Ghom	104.0°F	0.00897 lb/lb	14.9 tons	13.1 tons	12.08%
12	Tabriz	93.0°F	0.00896 lb/lb	12.6 tons	11.2 tons	11.11%

Table 1: Results of load calculations for restaurant buildings in selected cities of three zones.

Results

A study about using hybrid desiccant cooling system was done using some key variables, and then using each variable for a selection of some types of buildings and/or some. By compiling all of them, we can conclude:

- Industrial applications that need low dew points have a high potential of using this system, and sometimes the dew point is low enough that the decision does not need any detailed examination;
- In some commercial or institutional buildings that need special levels of indoor air humidity level or need special indoor air quality, use of these systems may be economical;
- Crowded buildings such as schools, restaurants, hospitals, mosques, etc., which are located in hot, semi-humid Region 2 are good candidates, although firm decision-making needs more detailed analysis.
- In the cities of highly humid Region 1, nearly any building that requires air conditioning is an excellent candidate for a desiccant-assisted system. In particular, those which have a high ventilation load requirement have a high potential for benefits from a desiccant-assisted system.

To check these zones, complete calculations were made for some building types. As an example, a typical layout has been prepared for a restaurant building consistent with the typical architectural standards. It has been modeled and its total loads calculated with conventional HVAC engineering software for some Iranian cities. The results show consistency of the selected zones with the calculated latent load fractions. The results for some of the cities are shown in *Figure 7* and *Table 1*.

The internal loads of the building consist of people, overhead lighting and kitchen appliances having about 6.2 tons (22 kW) of sensible refrigeration and 2.4 tons (8.5 kW) of latent refrigeration. The selected building has about 28% latent load in internal loads, which by taking into account the structure and window's loads, it will go below 25% as specified before. Load calculating results of *Table 1* show that the building satisfies the key variables in Zones 1 and 2 and does not satisfy the key variables in Zone 3, which confirms the mentioned results.

Conclusions

This article considers the possibility of using hybrid desiccant cooling systems instead of conventional vapor compression cooling systems through some key variables. These key variables can determine if a special building in an area needs a more detailed consideration.

Based on the information presented here, it appears that a high potential exists for using hybrid desiccant systems in Iran, suggesting opportunities for importing the technology, or for development of equipment locally.

References

1. Iran Management and Programming Organization. 2003. "Design Conditions."
2. Kasmaiee, M. 1990. "Climatic Classification of Iran for Housing and Residential Environments." Building and Housing Research Center, Iran.
3. www.wbdg.org/ccb/COOL/femp_ta.pdf.
4. Mazzei, P., F. Minichiello, D. Palma. 2002. "Desiccant HVAC systems for commercial buildings." *Journal of Applied Thermal Engineering,* 22:545–560.
5. B.S. Davanagere, Sherif, S.A., and Goswami, D.Y. 1999. "A feasibility study of a solar desiccant air conditioning system—Part II: transient simulation and economics." *International Journal of Energy Research*, 23:103 – 116.
6. Parsons, B.K., A.A. Pesaran, D. Gharathan, B. Shelpuk. 1989. "Improving gas-fired heat pump capacity and performance by adding a desiccant dehumidification subsystem." *ASHRAE Transactions*, 95:835–844.
7. *2001 ASHRAE Handbook—HVAC Applications*, chap. 29.
8. Carrier Corporation. 1965. *Handbook of Air Conditioning System Design.* New York: McGraw-Hill.
9. *2001 ASHRAE Handbook—HVAC Applications*, chap.26.
10. ANSI/ASHRAE Standard 62-1989, *Ventilation for Acceptable Indoor Air Quality.*
11. http://tarefe.tavanir.org.ir/.
12. Hessari, F.A. 2005. "Sectoral energy consumption in Iran." *Journal of Renewable & Sustainable Energy Reviews,* 9:203–214.
13. http://mgd.nigc.ir/MGD2/Default.aspx?PID=307.
14. U.S. Energy Administration. Natural Gas Data. www.eia.doe.gov/oil_gas/natural_gas/info_glance/natural_gas.html.
15. U.S. Energy Administration. Electricity Data. www.eia.doe.gov/fuelelectric.html.
16. Tavanir, Iran Power Generation, Transmission and Distribution Management. www.tavanir.org.ir.