The world is grappling with two serious issues related to energy and climate change. The use of solar energy is receiving much attention due to its potential as one of the solutions. Air conditioning is particularly attractive as a solar energy application because of the near coincidence of peak cooling loads with the available solar power. Recently, researchers have started serious discussions of using adsorptive processes for refrigeration and heat pumps. There is some success for the >100 ton adsorption systems but none exists in the <10 ton size range required for residential air conditioning. There are myriad reasons for the lack of small-scale systems such as low Coefficient of Performance (COP), high capital cost, scalability, and limited performance data. A numerical model to simulate an adsorption system was developed and its performance was compared with similar thermal-powered systems. Results showed that both the adsorption and absorption systems provide equal cooling capacity for a driving temperature range of 70-120 °C, but the adsorption system is the only system to deliver cooling at temperatures below 65 °C. Additionally, the absorption and desiccant systems provide better COP at low temperatures, but the COP’s of the three systems converge at higher regeneration temperatures. To further investigate the viability of solar-powered heat pump systems, an hourly building load simulation was developed for a single-family house in the Phoenix metropolitan area. Thermal as well as economic performance comparison was conducted for adsorption, absorption, and solar photovoltaic (PV) powered vapor compression systems for a range of solar collector area and storage capacity. The results showed that for a small collector area, solar PV is more cost-effective whereas adsorption is better than absorption for larger collector area. The optimum solar collector area and the storage size were determined for each type of solar system. As part of this dissertation work, a small-scale proof-of-concept prototype of the adsorption system was assembled using some novel heat transfer enhancement strategies. Activated carbon and butane was chosen as the adsorbent-refrigerant pair. It was found that a COP of 0.12 and a cooling capacity of 89.6 W can be achieved.