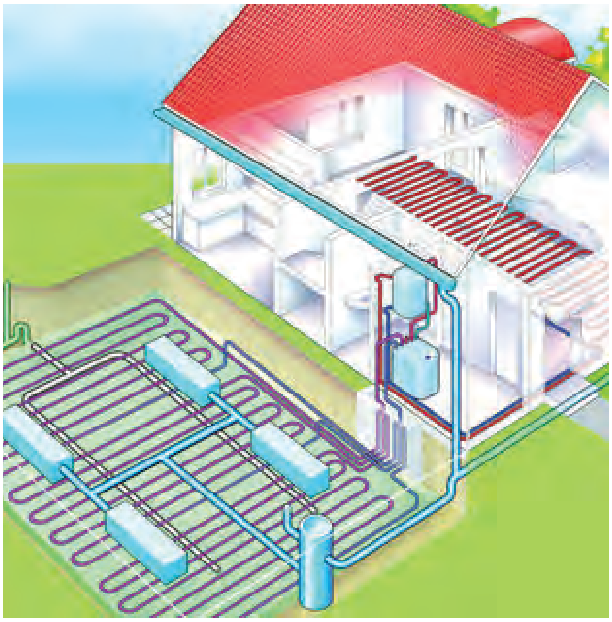
CEDRO
CEDRO, with energy efficiency on our mind
Country Energy Efficiency and Renewable Energy
Demonstration Project for the Recovery of Lebanon
Cedro Exchange Issue Number 6 - April 2013

Review of Heat Pumps Technology in Lebanon; Principle, Prospects and Barriers

Guest Author;
Elias Kinab, PhD, Energy Consultant, Lecturer at the American University of Beirut and the Lebanese University
elias.kinab@gmail.com

1. Introduction

CEDRO Exchange Issue 6 deals with the Heat Pumps technology that can be considered a renewable energy source, from a general, technical and economic point of view, although the energy input has to be carefully considered. This issue reviews the entire heat pump technology sector, the theory and application of various types of systems (air, ground and water). An evaluation of the heat pumps' application in Lebanon is presented thereafter, describing the prospects and barriers of this technology and the expected economic and environmental performances.



aecid
UNDP
Empowered lives. Resilient nations.
UNITED NATIONS DEVELOPMENT GROUP

2 - Principle

A heat pump is a thermodynamic system that transfers heat from a heat source to a heat sink and this is achieved with a mechanical compressional work. The compressor can be driven by an electric motor or an internal combustion gas engine. The cycle is composed of four components: compressor, condenser, expansion valve and evaporator (figure 1).

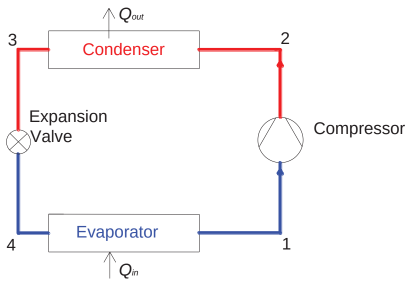


Figure 1: Heat pump components

A heat pump is called reversible (or reversible chiller) when it is used for heating or cooling depending on the configuration of the refrigeration cycle. The cycle inversion is provided by a 4-way valve, as shown in figure 2:

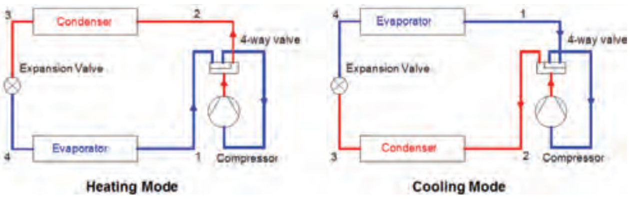


Figure 2: Reversing the cycle from heating mode to cooling mode by a 4-way valve (Kinab, 2009)

The thermodynamic vapor compression cycle is composed of four processes: compression 1-2, condensation 2-3, expansion 3-4, and evaporation 4-1 (Figure 3). A working fluid flows through the different stages of the cycle, which is a refrigerant such as R-134a or R407c or R410A.

In the evaporator, the heat is transferred to the refrigerant where its pressure and temperature are low. Herein, the work is done on the refrigerant in the compressor. The heat is then transferred from it to the condenser level where its pressure and temperature are elevated. The pressure drops as the refrigerant flows through the expansion valve or throttling device.

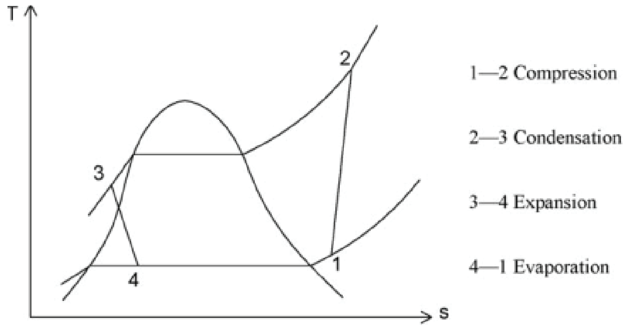


Figure 3: Thermodynamic vapor compression cycle (Temperature – Entropy diagram) (Kinab, 2010)

In this context, a heat pump in cooling mode (also called chiller) removes or transfers heat from inside a building to the outside. The internal unit(s) will play the role of an evaporator and the external unit(s) will play the role of a condenser. Conversely, in heating mode, the heat pump will extract the heat from outside the building and transfer it to the inside. The internal unit(s) will play the role of a condenser and the external unit(s) will play the role of an evaporator.

The heat pump is considered among the systems that exploit renewable energy, because it takes heat from the environment to heat the building from either air, ground or water. Recently, the European Parliament voted on the Renewable Energy Directive CE/28/200, acknowledging the heat contained in the air as «renewable energy» (Directive 2009/28/EC, 2009). A review of greenhouse gas emissions released (expressed as CO_2 equivalent) by a heat pump is later presented in this article for the Lebanese context, compared to traditional heating systems.

Performance of a heat pump is defined by the ratio of the desired heat capacity output (heating or cooling) to the power consumed by the compressor and the auxiliaries.

In heating mode, the 'Coefficient of Performance' COP is the ratio of heating capacity output to the power consumption:

$$COP = \frac{Q_{heating}}{P_{consumed}}$$

In cooling mode, the 'Energy Efficiency Ratio' EER is the ratio of cooling capacity to the power consumption:

$$EER = \frac{Q_{cooling}}{P_{consumed}}$$

The defined performances of a reversible heat pump system are limited by the source and the sink temperatures and the maximal theoretical performances correspond to the ideal Carnot cycle, in heating mode:

$$COP_{Carnot} = \frac{T_h}{T_h - T_c}$$

and in cooling mode:

$$EER_{Carnot} = \frac{T_c}{T_h - T_c}$$

where the temperatures are expressed in Kelvin.

Lately, heat pumps' manufacturers expressed the performance by seasonal performance SCOP and SEER which quantify the average annual performance of the installed heat in a building in a certain climate providing the coefficient of performance at partial load (Kinab, 2008 & Rivière, 2008).

One of the major advantages of heat pumps is their low electrical energy consumption in relation to the thermal energy output; for example a coefficient of performance (COP) of 4 means that for each 1 kWh of electricity consumed, approximately 4 kWh of thermal energy is returned to the building. Thereupon, heat pumps are used to limit the use of conventional energy sources and emissions of some pollutants that have a significant impact on the greenhouse effect. A 1 kWh of heat produced through a heat pump generates about four times less CO_2 than a 1 kWh of heat produced by a fuel boiler. In addition, for the same comfort, a heat pump can significantly drop the emissions of certain other pollutants (NO_x and SO_2 in particular). Consequently, heat pumps are an interesting solution that respects the environment and promotes natural renewable energy (sun, wind, and rain) stored in the ground, in the air and in the groundwater.

3 - Heat Pumps Technologies

3-1 Air Source Heat Pump (ASHP)

Air source heat pumps (ASHPs) draw heat from the outside air during the heating season and eject heat to the outside during the summer cooling season. There are two types of air-source heat pumps. The most common is the air-to-air one. It extracts heat from the air and then transfers heat to either the inside or outside of the building depending on the season. The other type is the air-to-water heat pump, which is used in buildings equipped with a water distribution circuit system (hot water/ chilled water). During the heating season, the heat pump takes heat from the outside air and then transfers it to the water in the heating circuit. If cooling is needed during summer, the process is reversed: the heat pump extracts heat from the chilled water circuit in the building and «pumps» it outside to cool the inside of the building. Air-source heat pumps have also been used in some ventilation systems to recover heat from outgoing stale air and transfer it to incoming fresh air.

Figure 4: Air source heat pump (AFPAC, 2013)

Air source heat pumps are the most widespread/ popular type since they are relatively simple and inexpensive to install. However, this type of heat pumps directly depends upon the outside air's temperature which can vary randomly thereby limiting the performance. For instance, in the summer cooling season, the performance of reversible heat pump decreases with the increase of the air temperature. Similarly, in the winter heating season the performance of a reversible heat pump decreases with the decrease of the air temperature. Besides, at low temperatures and high humidity issues related to outside air conditions, like frost and defrost problems occur on the outside heat exchanger (evaporator).

Recently, a new configuration has been added to this a conventional ASHP. That configuration takes advantage of the exhaust of air of a building where there is mechanical ventilation. In the winter heating season the exhaust air is at higher temperature from the outside air temperature will be a better heat source for the evaporator, and in the summer cooling season it is at lower temperature and could better cool the condenser.

3-2 Ground Source Heat Pump (GSHP)

The ground temperature slightly varies in comparison with air temperature regardless of the time of year. Indeed, it is not influenced by outside air, even in cold climates, where the upper layer acts as an insulator. However, the sun and water infiltration accumulate heat in the surface soil layers.

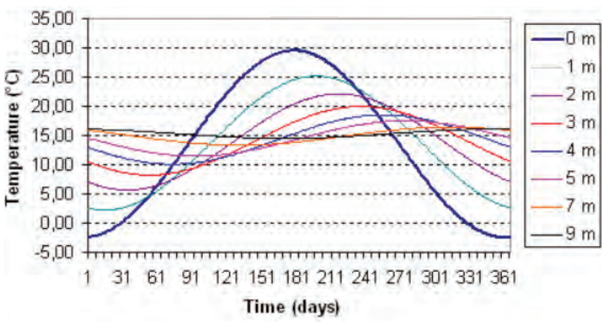


Figure 5: Temperature in the ground according to the depth (Thiers, 2009)

GSHP extracts solar heat stored in the upper layers of the earth; the heat is then delivered to the building. Conversely, in the summer season, the heat pump rejects heat removed from the building into the ground rather than into the atmosphere or a body of water.

There are two main types of earth heat exchangers for the geothermal heat pump: the horizontal heat exchanger, and the vertical heat exchanger (borehole) as shown in the figure below. The vertical boreholes are used when a land area is a constraint; their installation is relatively more expensive than horizontal heat exchanger. The UNDP-CEDRO project has delivered one such project in Bejji Municipality, Mount Lebanon (see CEDRO website for more information).

Figure 6: Ground source heat pump (GSHP)

(a) Horizontal heat exchanger, (b) vertical heat exchanger (AFPAC, 2013)

Also, the heat transfer between the system and the ground can be through a closed loop or an open loop, depending on the soil's characteristics.

Figure 7: Open loop (right) and close loop (left) geothermal heat exchanger (CEDRO, 2012)

The heat capacity stored in the ground is directly related to the soil's characteristics and material type (clay, silt, sand, and rock) in terms of thermal conductivity and thermal capacity (see Table 1).

	Thermal conductivity (W/m.K)		Thermal capacity (MJ/m³.K)	
Material	dry	Saturated	dry	saturated
Clay	0.2 - 0.3	1.1 - 1.6	0.3 - 0.6	2.1 - 3.2
Silt	0.2 - 0.3	1.2 - 2.5	0.6 - 1.0	2.1 - 2.4
Sand	0.3 - 0.4	1.7 - 3.2	1.0 - 1.3	2.2 - 2.4
Rock	1.8 - 3.3		1.8 - 2.3	

Table 1: Soil thermal characteristic (CEDRO, 2012)

As with the ASHPs, GSHPs can reduce the energy required for space heating, cooling, and service water heating in buildings. Ground source heat pumps replace the need for a boiler in winter by utilizing heat stored in the ground; this heat is upgraded by the vapor-compressor refrigeration cycle. There are two main types of ground source heat pumps:

- The ground – air heat pump (transfers heat to / extracts heat from the inside air of the building)
- The ground – water heat pump (transfers heat to / extracts heat from the hot/chiller water circuit in the building)

Also, GSHPs eliminate the need for a cooling tower or air heat exchanger and lower operating costs. The ground is also cooler than the outdoor air, leading to higher performances compared to air source heat pumps. However, the initial investment of drilling and installing earth heat exchangers is high.

3-3 Water Source Heat Pump

The water source heat pump uses water as a source or sink for heat instead of air or ground. Common examples include, a flowing river, a lake, seawater, underground water…

Figure 8: Ground source heat pump (AFPAC, 2013)

Reversible heat pumps equipped with a cooling tower are also considered water source heat pumps.

3-4 Solar Assisted Heat Pump

The solar assisted heat pumps are used for heating and domestic hot water production purposes. The solar energy collected by the solar thermal panels at the evaporator stage of the heat pump cycle, enhance the heat source condition, leading to high temperatures at the condensor stage and therefore high coefficients of performance.

3-5 Absorption Heat Pump

The absorption heat pump substitutes the compressor of the conventional heat pump vapor compression cycle by a small liquid pump and two heat exchangers (absorber and generator) in which a reversible chemical occurs between the refrigerant and the absorbent. Pairs of refrigerant and absorbent exist such as H_2O / LiBr solution

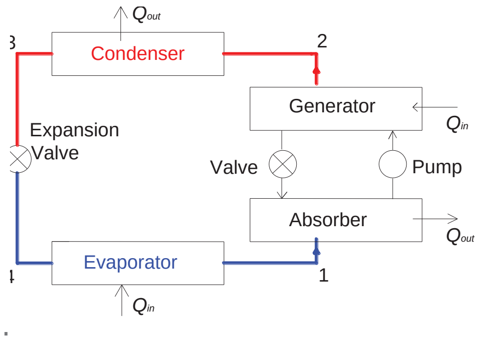


Figure 9: Absorption heat pump

After the refrigerant absorption reaction at the absorber level, the pump brings the rich solution of refrigerant (H_2O) towards the high-pressure zone; the mixture is heated in the generator. A contribution of heat (waste heat or solar energy) allows the separation of the refrigerant (H_2O) from the absorbent (LiBr solution).

$LiOH + HBr \rightarrow LiBr + H_2O$ (endothermic reaction)

Then the vapors of refrigerant (H_2O) are sent towards the traditional cycle of condenser, expansion valve and evaporator.

Meanwhile, the poor solution of refrigerant (H_2O) turns over in the absorber by passing by a pressure-relief valve, where the vapor of refrigerant is absorbed by this poor solution coming from the generator at absorber. The cycle can start again.

$LiBr + H_2O \rightarrow LiOH + HBr$ (exothermic reaction)

The absorption cycle has the advantage of low electric consumption and it can use solar energy as a source of heating for the generator. However, the coefficient of performance is lower than the traditional cycle, and in terms of compactness the volume of system is doubled (4 heat exchangers instead of 2).

4 - Principle of operation of a heat pump

The sizing of a heat pump is made according to the type of building and its thermal load (thermal needs in cooling and heating), heat emitters and climate.

Several types of emitters exist. In the case of air – to – water heat pump (the most widely used), the water distribution circuit temperature depends on the type of emitters used, and this directly affects the design of the heat pump. In heating mode, water temperature laws (lois d'eau) exist. They allow controlling the temperature of the water circuit as a function of the outside air temperature and the inertia of the building. The interest of the water temperature law is to adapt the level of supply temperature to the heating load. Also, in cooling mode, the temperature levels are controlled as a function of different types of cold distributors

In heating mode, the values of water temperature commonly used for heat pumps emitters are:

- Radiator (T water supply = 65 °C for T outside air = -12 ° C)
- Fan coil (T water supply = 45 °C for T outside air = -12 ° C)
- Underfloor heater (T water supply = 35 °C for T outside air = -12 ° C)

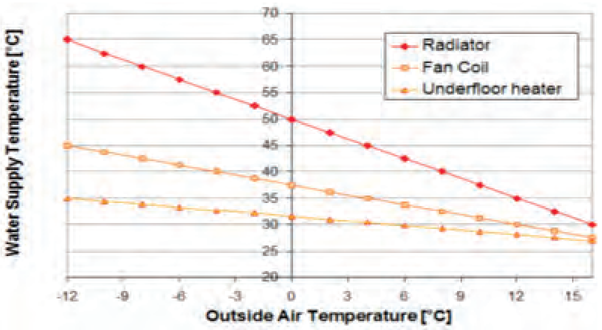


Figure 10: The water temperature law depending on the type of emitter in heating mode

The heating capacity, delivered by the heat pump, decreases with low external temperatures which also penalize the performance of the machine, while the heating requirements increase at these conditions, demanding an initial higher supply temperature. Therefore, an auxiliary heating system is needed; it can be provided by electric heaters or boilers.

The operation of a heat pump with auxiliary is described in Figure 11:

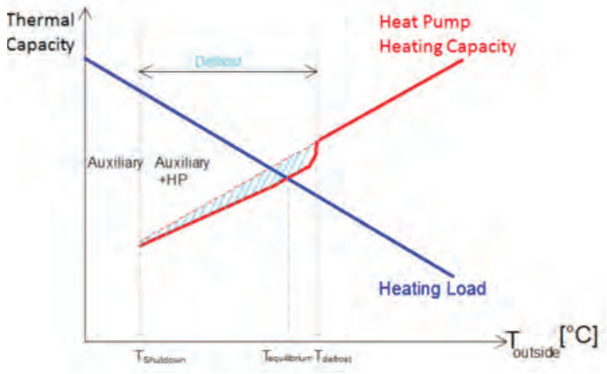


Figure 11: Operation of a heat pump in heating mode

The equilibrium temperature is the outdoor temperature at which the heating capacity of the heat pump is equal to the heating load of the building. At this temperature, the heat pump operates continuously, while for temperatures higher than the equilibrium temperature, the heat pump operates at a partial load.

The shutdown temperature is the outdoor temperature at which the heat pump is stopped for technical constraints which correspond to a rate outside the range of compressor operation. The operating range of the heat pumps reflects the compressor's range.

The need to defrost the air heat exchanger depends on the temperature of the surface in contact with air when Tcontact is lower than 0 ° C, which in general is summarized by an outdoor temperature T outside air lower than 7 ° C, and air humidity higher than 50 %. This operation point is defined by the standards. Manufacturers have made the effort to reduce the temperature difference between the evaporation temperature and the outdoor air temperature to prevent frost at these conditions.

For temperatures below the equilibrium temperature and above off temperatures, the heat pump operates continuously assisted by an auxiliary heating system, while for outdoor temperatures less than the shutdown temperature, the auxiliary heating system responds alone to the heating needs.

In cooling mode, the operating temperatures of the different types of cooling emitters:

- Fan coil (T water supply = 12 °C for T outside air = 35 °C)
- Chilled ceiling (T water supply between 16 °C and 18 °C)
- Chilled beam (T water supply between 16 °C and 18 °C)

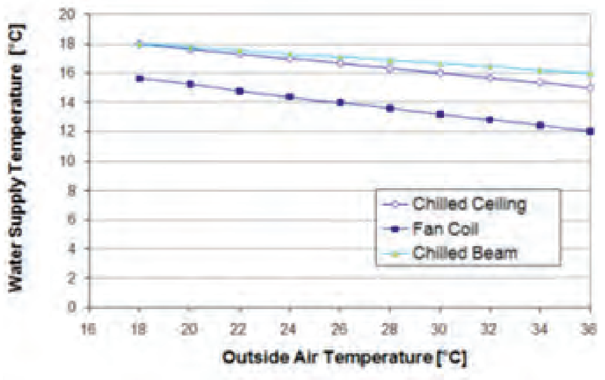


Figure 12: The water temperature law depending on the type of emitter in cooling mode

The design or the sizing of a reversible heat pump results from the priority need in cooling or heating mode.

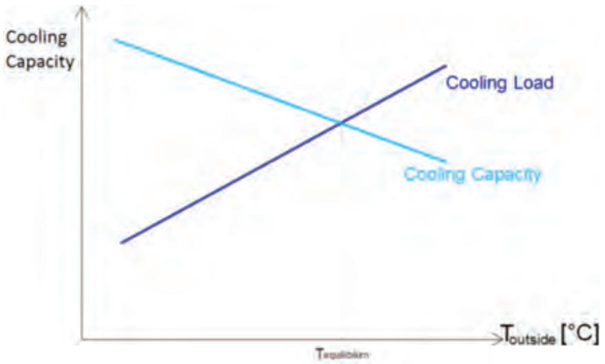


Figure 13: Operation of heat pump in cooling mode

5 - Heat Pumps Technology in Lebanon

5-1 Thermal comfort; an economic and environmental energy challenge

The augmentation of the building sector in Lebanon manifested by the registration/authorization of 15,175,926 m^2 of new building area for construction in 2010 according to the Order of Engineers and Architects in Beirut (OEA 2013), is accompanied by the installation of air conditioning systems necessary for human thermal comfort.

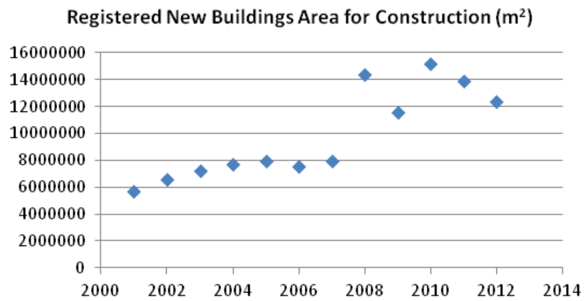


Figure 14: Evolution of building registered areas in Lebanon (OEA, 2013)

Figure 14 shows the evolution of new building floor area constructed in Lebanon between 2001 (5,722,850 m^2) and 2012 (12,367,081 m^2). The heat pump air conditioning system type depends on the building typology.

Heat pumps accounted in this study are considered residential systems when their nominal capacity is below 17.5 kW and commercial systems when their nominal capacity is above 17.5 kW.

Table 2 below outlines the heat pump destination by new building type; residential buildings constructed in 2011 and 2012 are about 80 %, while commercial buildings are only around 20 %.

		2011	2012
Type		Percentage (%)	Percentage (%)
Residential		83.1%	79.1%
	Retail	6.9%	10.0%
	Hotels	2.6%	1.2%
	Schools hospitals	1.2%	3.4%
	Industrial, Agriculture	4.8%	4.7%
	Other	1.5%	1.6%
Total		100.0%	100.0%

Table 2: Heat pumps destination by new registered/ authorized building type (OEA 2013) in Lebanon

The increasing application of air conditioning systems in the commercial sector is also followed by an increase in sales of air conditioners in the residential area. These thermal systems contribute to power consumption, as well as the CO_2 emissions and the high energy costs.

Local guidelines are developed by national and international governmental and nongovernmental organizations (LGBC, LIBNOR, LCEC…). They aim to reduce this consumption by increasing the energy efficiency of these systems.

The Lebanese electricity mix is dominated by conventional thermal power plants. 98% of the energy produced in Lebanon is mainly provided from the use of imported petroleum products (El Fadel, 2001). In addition, the remaining 2% are produced from the hydroelectric plants available in the country, and some biomass products such as wood. Like most developing countries, the generation of energy in Lebanon is inefficient. The main producer is EDL (Electricite du Liban).

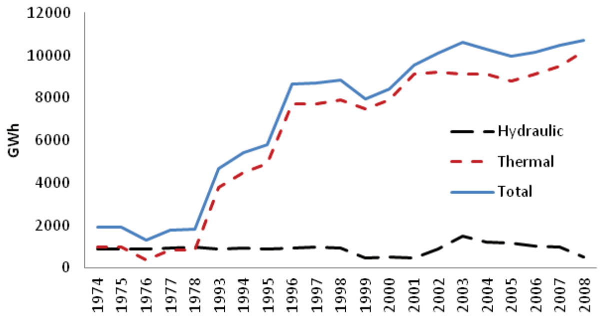


Figure 14: Evolution of electricity production (Kinab, 2012)

Therefore, the specificity of the Lebanese electricity generation in terms of emissions of greenhouse gases, is its relatively high CO_2 content per kWh of electricity consumed which is 667 g CO_2/kWh on average (UNEP, 2009), compared to the European average of about 340 g CO_2/kWh.

Subsequently, the electric boiler or heater emits 667 g CO_2/kWh compared to lower values of natural gas boiler with 206 g CO_2/kWh and diesel boiler with 252 g CO_2/kWh.

For the case of a heat pump used as a heating device, with a coefficient of performance of 4 as described earlier, for every 1 kWh electricity consumed, 4 kWh of thermal energy, leading an equivalent of 667/4 = 167 g CO_2/kWh.

Therefore, to be environmentally feasible under the Lebanese electricity conditions, heat pumps have to have a seasonal coefficient of performance higher than 3.24 otherwise gas will be more beneficial.

This is not the case of France, for example , where electricity generation is dominated by clean nuclear power leading to a content of CO_2 per kWh of electricity consumed between 60 and 120 g CO_2/kWh, extremely encouraging the heat pumps for heating.

Concerning the economic side of the use of heat pumps, it presents an advantage which is the interchangeable use of the same system for cooling and heating. However, it depends on the situation of the electricity sector in Lebanon and its availability. Even though the current kWh prices are very competitive (given they are subsidized), but the shortage of electricity is crucial and conventional gas or diesel boiler are better current solutions for heating. Therefore, burning gas or diesel directly is a better solution. In cooling mode, the choice doesn't exist; reversible heat pumps are the only current solution with the absence of passive cooling systems.

5-2 Place of heat pumps on the Lebanese market of air conditioning

Unfortunately, there are no official statistical data about the heat pumps market in Lebanon. However, a simple model from the available registered/authorized new building areas (OEA, 2013) can deduce the thermal capacity installed.

Effectively, the number of units can be expressed by the corresponding heat pump heated floor area through this equation:

F= (N×P)/D

where:

- N is the number of units, and P the nominal heating capacity of the unit (W), their product corresponds to the capacity installed.
- D the heating density (W/m²)
- F the area heated (m²)

Heating density values D are issued from the sizing of the heat pump according to building type, climate, national habits, etc. For example, a heating density of 100 W/m² is attributed to a residence in Beirut, and 140 W/m² for the same residence in Zahle, while for commercial buildings heating densities are estimated to 60 W/m² in Beirut and 75 W/m² in Zahle.

In the context of Lebanon, average values for the heating densities can be assumed according to the different provinces (Table 3) and the number of units can be consequently estimated (Table 4).

Province	2012 (m²)	%
Beirut	1086382	8.8%
Mount Lebanon	7366043	59.6%
Bekaa	1274313	10.3%
South	1558789	12.6%
Nabatiyi	926766	7.5%
North	154788	1.3%
Total	12367081	100.0%

Table 3: Geographical distribution of new building constructed areas in 2012 (OEA, 2013)

Province	D (For Residential Buildings) W/m²	D (For Commercial Buildings) W/m²
Beirut	100	60
Mount Lebanon	140	75
Bekaa	150	80
South	120	70
Nabatiyi	120	70
North	140	75

Table 4: Estimated average values for the heating densities

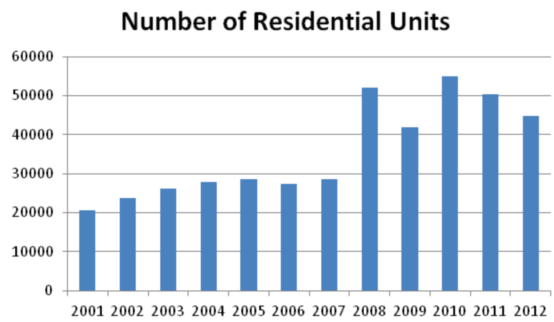


Figure 15: Evolution of residential heat pump units

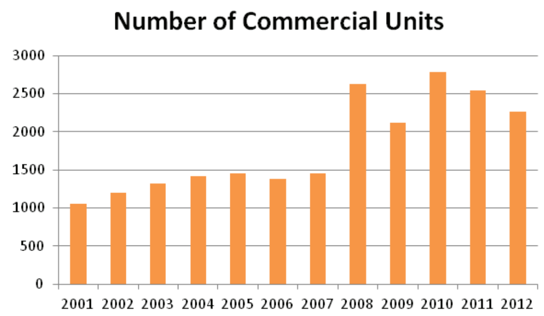


Figure 16: Evolution of commercial heat pump units

Conclusion

This issue has presented a description of Heat Pumps technology, from a general and technical point of view. It has reviewed the entire heat pump technology sector, the theory and application of various types of systems (air, ground and water). An analysis on the heat pump technology application in Lebanon was presented discussing both the environmental and the economic aspects. The unstable current electricity situation doesn't encourage installers to adopt heat pumps for heating instead of conventional gas or diesel boilers. However, for the case of cooling, reversible heat pumps are the only current solution with the absence of passive cooling systems.

Finally, heat pumps with high seasonal coefficients of performance have to be adopted, following a Lebanese norm that needs elaboration so it can define the selection of heat pumps specifications according to the geographical location of the building, building type and emitters' type.

REFERENCES

- DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.
- E. Kinab. 2009. Part load optimization of commercial heat pumps. Ph.D. Thesis, Ecole des Mines de Paris, 2009.
- E. Kinab et al. 2010. Reversible heat pump model for seasonal performance optimization. Energy and Buildings 42 (2010) 2269–2280.
- E. Kinab, D. Marchio, P. Rivière, Seasonal coefficient of performance of heat pumps, in: Proceedings of the 12th International Refrigeration and Air Conditioning Conference at Purdue, 2008, p. 2312.
- P. Rivière, E. Kinab, D. Marchio, Performance saisonnière des pompes à chaleur, PERSAPAC Project, Rapport intermédiaire ADEME/ARMINES contract no. 0507C0073, 2008
- AFPAC 2013. Association française des pompes à chaleur. http://www.afpac.org
- S. Thiers. Energy and environmental assessments of energy-producing buildings. Ph.D. Thesis, Ecole des Mines de Paris, 2008
- CEDRO 2012, Unai Arrieta, Pol Arranz, Xavier Vallvé, Introduction to Ground Source Heat Pump Systems Trama Tecnoambiental, Spain
- OEA 2013, Annual Report 2012, Order of Engineers and Architects of Beirut, http://www.oea.org.lb
- CEDRO – UNDP Project, "Country energy efficiency and renewable energy demonstration project for the recovery of Lebanon", http://www.cedro-undp.org
- LCEC, Lebanese Center for Energy Conservation, http://lcecp.org.lb
- LGBC, Lebanese Green Building Council, http://www.lebanon-gbc.org
- E. Kinab, M. Elkhoury. 2012. Renewable energy use in Lebanon: Barriers and

solutions. Renewable and Sustainable Energy Reviews 16 (2012) 4422–4431.

- El-Fadel M, Massoud M, Semerjian L. Energy related GHG emissions: assessment of emission factor uncertainty. World Resource Review 2001;13(1):61–73.
- UNEP's Greenhouse Gas Calculator, UNEP, 2009

Empowered lives,
Resilient nations.

Beirut, Maarad street, Building 287 B, 1st floor, Lebanon
T/F: +961-1-981944
info@cedro-undp.org
www.cedro-undp.org