SUSTAINABLE H/C SYSTEMS FOR CHICKEN FARMS IN SYRIA

Mohamad Kharseh[1], Bo Nordell[2]
[1] Dept. of Civil and Environmental Engineering, Luleå University of Technology
SE-97187 Luleå, Sweden, khamoh@ltu.se
[2] Dept. of Civil and Environmental Engineering, Luleå University of Technology
SE-97187 Luleå, Sweden, bon@ltu.se

ABSTRACT

Space heating/cooling systems account for approximately 30% of the global energy consumption. Such systems contribute to global warming by emitting $0.39.10^{11}$ MWh of heat and $2.9.10^{10}$ tons of CO_2. There is a general understanding that the way to reduce global warming is a more efficient use of energy and increased use of renewable energy in all fields of the society.
The poultry industry in the Mid East is an important business. There are e.g. 13000 chicken farms in Syria producing 172,000 ton of meat. This industry employs directly almost 150,000 people. The total investment in chicken farming is 130 BSP (2 B€).
Even though, the annual mean temperature in Syria is ~15-18°C the winter temperatures are close to freezing for two months. Since the chickens need a temperature of 21-35°C, depending on age, approximately $168 \cdot 10^3$ tons of coal (1170 GWh) is consumed for heating these plants. The chicken farms have no cooling systems since conventional cooling is too expensive. In the summer time, the ambient air temperature in Syria could reach above 45°C. The elevated temperature inside the farms reduces the chicken growth and lots of chicken die of over heating.
Using the ground as a heat source means a sustainable and less expensive heating of the chicken farms. During the summer the resulting colder ground can be used as a source for free cooling, i.e. it can be used directly for cooling of the plants without any cooling machines.
This study shows the design and simulated operation of a ground coupled heating/cooling system for a typical chicken farm in Syria. Based on this study the national potential of using such systems was estimated. It shows that the implementation of such ground coupled heating and cooling systems in the Syrian poultry sector would mean increased poultry production and considerable savings in money, energy, and the environment.

KEYWORDS: ground coupled, heating, cooling, chicken farm, CO_2 emission, thermal pollution.

INTRODUCTION

The global energy consumption is 1.3.10[11] MWh/year, partly covered by a daily oil consumption of 82.6 Mbbl (2004 est.)[CIA]. The CO_2 emission, which is supposed to play a leading role in global warming, is about 2.65 ton-CO_2/m^3 of oil [Genchi et.al, 2002]. This means that oil alone results in an annual emission of 1.25.10[10] tons of CO_2. Global oil production peaked more than two years ago [Oil production has already peaked and Peak Oil]. Since there is no possibility to increase the global oil production, cost of oil will increase.

Space heating/cooling systems consume about 30% of global energy consumption [Ala-Juusela] (oil, gas, coal etc.), i.e. 3.9.10[10] MWh/year corresponding to emission of 2.9.10[10] tons CO_2/year. The Syrian oil production (Fig.1), which has declined from $600 \cdot 10^3$ bbl/d in 1996 to $396 \cdot 10^3$ bbl/d in 2007, is projected to continue its decline [CIA, Energy Information Administration and Syria Energy and power] and is projected to equal Syrian consumption in 2011.

The foreseen environmental problems require long-term actions for sustainable development. In this regard, more efficient use of energy and increased use of renewable energy (RE) appear to be the most efficient and effective solutions [Hepbasli and Nordel]. However, the problem is that most types of renewable energy are available when the demand is low [Nordell et.al]. One example is that (Fig.2) the solar energy is available during the warm season, when heating demand is low, while it is relatively low during the cold season, when heating demand is high. Moreover, during the summer, night cold is available when the cooling demand is low (Fig.3). So, thermal energy storage is needed to bridge this gap in demand and supply. The ground is very suitable for thermal energy storage or as a sink or source of thermal energy.

Here, we focus on the very important chicken industry in Syria to show how underground thermal energy storage, UTES, enables a more efficient use of energy and increased use of renewable energy.

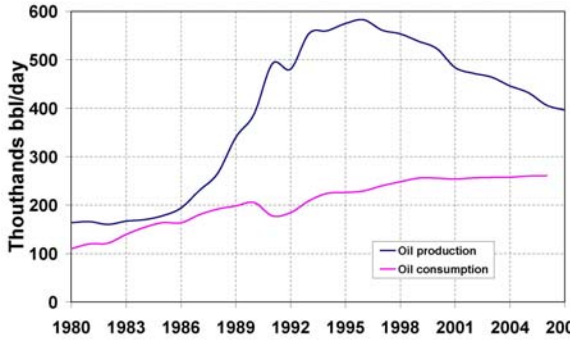

Fig. 1. Syrian oil production and consumption.

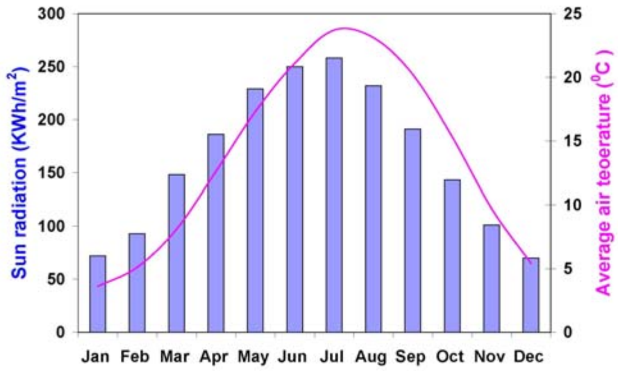

Fig. 2. Available solar energy and average air temperature in Hama, Syria, over an entire year

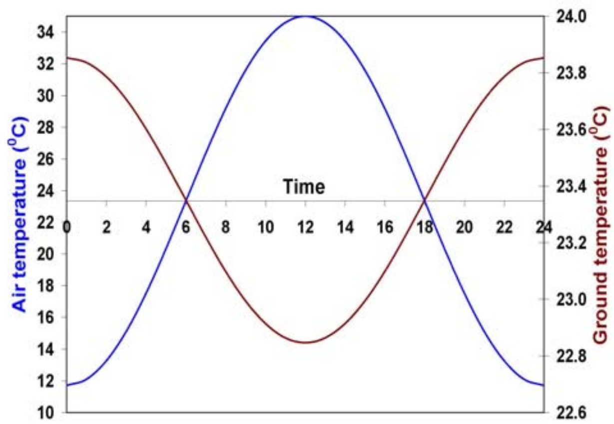

Fig. 3. Air and 63 Cm underground temperature variation over entire summer day

Problem

Almost 150 000 people work at the 13,000 chicken farms in Syria, which produce 172,000 ton of meat. The total investment in this important industry is 130 BSP (70 SP = 1 €). Even though the annual mean temperature in Syria is 15-18°C (Fig.4) heating of such farms, consume considerable amounts of energy. The reason is that the air temperature is close to freezing during three winter months (Table 1) and that chickens require a relatively high temperature, 21-35°C, depending on age (Table 2). The estimated total annual heating demand of these plants is 1170 GWh (Table 3). The conventional heating systems, i.e. coal furnace, consume $168 \cdot 10^3$ tons of coal assuming a conversion efficiency of 85% and that the specific heat of coal is 8.141 kWh/kg. The chicken farms have no cooling systems since conventional cooling is too expensive, though the ambient air temperature could reach above 45°C during the summer.

A suitable temperature is important for the chicken growth[1], which is ~60% during the winter and ~45% during the summer. The interpretation is that heaters control the temperature in the chicken farm during the winter while it is often gets too hot during the summer. Furthermore, since lots of chicken die from overheating during hot days, inexpensive cooling would mean an important improvement.

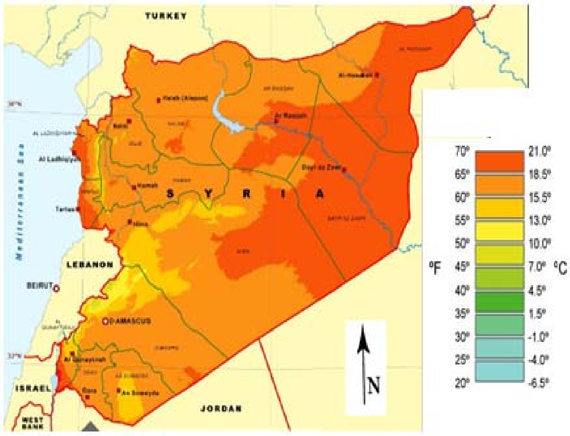

Fig. 4. Undisturbed ground temperature in Syria.

Solution

Ground coupled heat pump systems (GCHP) exploit effectively the heat of the ground [Florides et.al]. It can be used anywhere in the world to save energy and environment [John et.al] and presently more than one million systems are in operation in US and Europe, mainly in Sweden, Germany, and Switzerland. From an economical point of view, low operating and maintenance cost mean that these systems generally have attractive life-cycle costs. The construction cost of the ground heat exchangers (GHE) is critical for the economical competitiveness of GCHP systems in the heating and air-conditioning market.

Table 1 monthly temperature over entire year, Hama, Syria.

Month	Mean Air Temperature T_a (°C)	10 y Min Air Temperature $T_{a,\,min}$ (°C)	10 y Max Air Temperature $T_{a,\,max}$ (°C)	Daily Min Temperature $T_{a,dmin}$ (°C)	Daily Max Temperature $T_{a,dmax}$ (°C)
Jan	6.6	-3.4	17.2	2.3	10.8
Feb	8.3	-2.6	17.5	2.8	13.4
Mar	11.6	0.1	25.1	5.8	17.2
Apr	15.9	3.5	30.7	8.9	21.8
May	21.1	7.6	33.8	13.2	28.1
Jun	25.8	14.2	37.9	17.7	32.4
Jul	28.2	16.9	40.2	20.7	34.8
Aug	27.9	17.7	38.9	20.5	34.5
Sep	25.3	13.5	36.1	17.6	31.9
Oct	19.3	7.1	34.2	12.4	26.0
Nov	12.7	0.1	25.8	6.4	18.3
Dec	7.9	-0.9	18.7	3.6	12.1

Table 2 Appropriate indoor temperature in chicken farms.

Age of chicken	Temperature at 0.10-0.15 m level
(weeks)	(°C)
1	35
2	32
3	29
4	27
5	24
6 (fully grown)	21

Although Syrian local conditions in many ways are more favorable than in Sweden, such systems do not exist in Syria. Using the ground as a heat source means a sustainable and less expensive heating of the chicken farms. During the summer the resulting colder ground can be used as a source for free cooling, i.e. it can be used directly for cooling of the plants without any cooling machines.

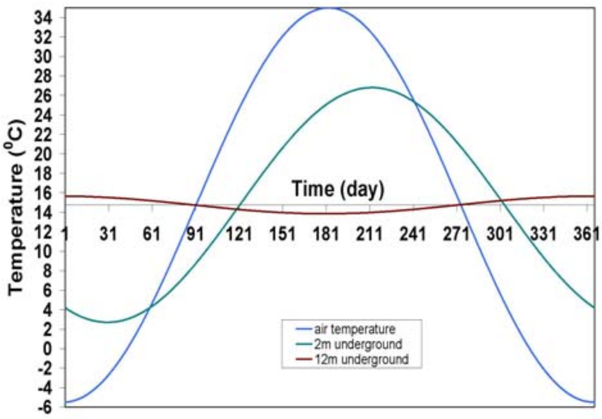

Fig. 5. Temperature variation of air and ground at depth 2 m and 12 m, in Hama, Syria

Theory

Ground coupled heating/cooling systems depend on the fact that the ground temperature (Fig.5) equals the annual mean air temperature at a certain depth below ground surface [Nordell and Omar]. In a climate with seasonal temperature variations, this gives the potential to use the underground as heat source (low temperature heat reservoir) during the cold season and as heat

[1] A chicken growth of 60% means that the weight increase is 60% of their feed.

sink (high temperature heat reservoir) during the hot season [Nordell et.al and Ozgener et.al]. Extracted thermal energy is renewable since the seasonal temperature variation restores the temperature from ground surface. According to the second law of thermodynamics, the coefficient of performance (COP) of a heat pump cycle is influenced by the operating conditions (condensation and evaporation temperatures). Its highest COP is obtained when the cycle is reversible (without exergy losses i.e. the adiabatic operations are isotropic and heat transfer operations are isothermal) and operating at the Carnot limit, (Fig.6). In this case, the COP is a function of the high temperature heat reservoir (HHR) and low temperature heat reservoir (LHR):

During winter (heating machine):

$$COP_h = \frac{T_{high}}{T_{high} - T_{low}}$$

Here, Thigh represents the condensation temperature, while Tlow represents the evaporation temperature. As seen, COP_h will increase if the T_{low} increases.

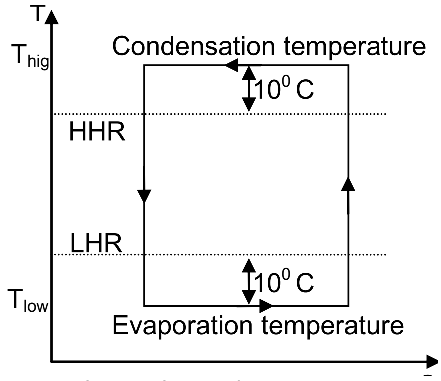

Fig. 6. Carnot Cycle of heat pump

During summer (cooling machine):

$$COP_c = \frac{T_{low}}{T_{high} - T_{low}}$$

Here, T_{low} represents the evaporation temperature, while T_{high} represents the condensation temperature. As seen, COP_c will increase if the T_{high} decreases.

Figur 7 shows the theoretical COP for heating and cooling machines.

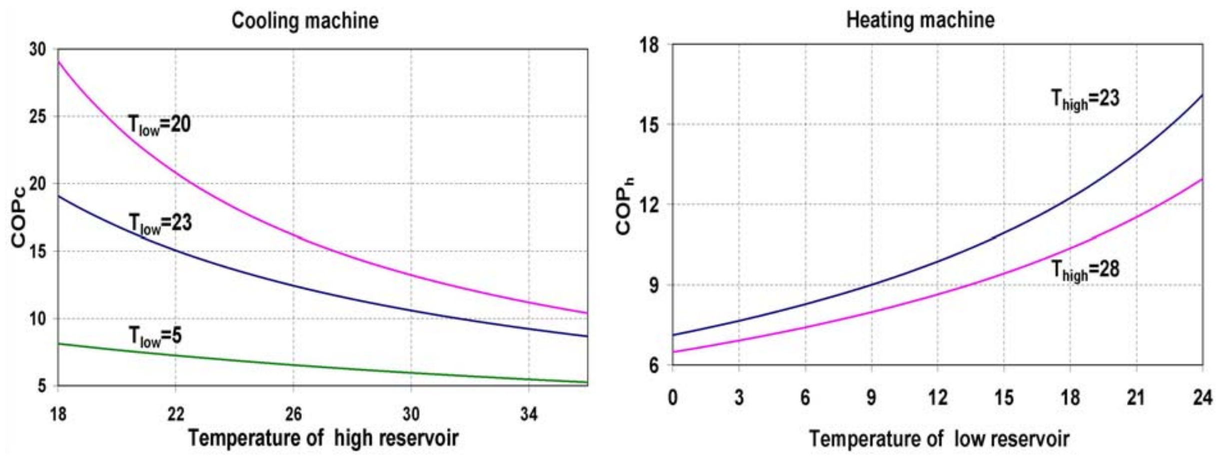

Fig. 7. COP as a function of low/high reservoir temperature.

a) <u>Heating machine;</u> T_{high} is 10 ^{0}C higher than inside temperature. While T_{low} is 10 ^{0}C lower than outside temperature (in ASHP case) or underground temperature (in GSHP case).
b) <u>Cooling machine;</u> T_{low} is 10 ^{0}C lower than inside temperature. While T_{high} is 10 ^{0} C higher than outside temperature (in ASHP case) or underground temperature (in GSHP case).

Since the ground temperature equals the annual mean air temperature it is colder than the air temperature during the summer and warmer during the winter. Therefore, ground source heat pump (GSHP) systems are inherently more efficient than an air source heat pump (ASHP) system [Genchi, Ozgener et.al, and Diao et.al]. Theoretically, the COP of GSHP heating systems in Syria will be 190% greater than that of ASHP systems, see Fig.7.

Case Study – the Kharseh chicken farm

The Kharseh chicken farm in Hama, Syria, (Fig.4) was selected as a study case for a GSHP heating and cooling system combined with solar collectors.
Reasonable assumptions were made for e.g. the thermal properties of the ground. In a planned and more detailed study, these ground properties will be determined by in-situ measurements and current assumptions will be adjusted.

The hangar is placed parallel to the main wind direction. Some relevant data are:

- Building area: 500 m^2 (50 m x 10 m) in E–W direction.
- Windows area: 12 m^2 on each side
- Indoor air temperature: 21^{o}C - 35^{o}C (see Table 2).
- During their first day, the chickens occupy about 85 m^2 of the building. This area is increased 14 m^2 per day until they occupy the full area after about one month.
- Thermal resistance of wall and ceiling is assumed about 0.28 K.m^2/W
- Ventilation rate 20 m^3/m^2,h (ventilated area of chicken farm varies with chicken age)
- Heat release from chickens: 50 W/m^2 (varies with age)
- The capacity of hangar is 5000 chickens (50-55 days each cycle life), which with 5 cycles/year, means and annual production of 25000 chickens or 33 tons of poultry meat.

Mean heating load

Occurring heat losses from the building, see Fig.8, is a result of:

- Heat conduction through walls, ceiling, floor and windows
- Ventilation air

Mean Cooling load

The required cooling demand depends on:

- Conduction through the wall, ceiling and windows
- Solar radiation
- Ventilation air
- Heat released by chickens.

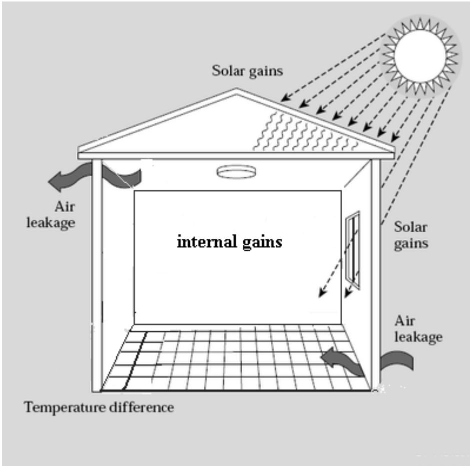

Fig. 8. Heating & cooling load

Heating/Cooling demand

The area of the hangar, occupied by the chickens, varies with time or size of the chickens. Therefore, heat emissions, required ventilation, heating and cooling also vary with time. Fig.9 shows the estimated heating/cooling power as the chickens grow during the hottest and coldest period of the year. Due to increasing occupation area, which means more heat conduction through a wall as well as more ventilation air, the required power increases with time both winter and summer. However, during heating season, the heating power increases with time until it peaks in the middle of the chickens' life cycle since the appropriate temperature is lowered with age. This peak demand does not occur during the cooling season (Fig.10).

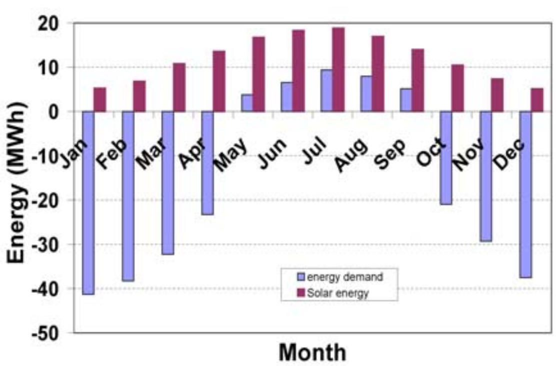

Fig. 9. Monthly heating/cooling demand and solar yield

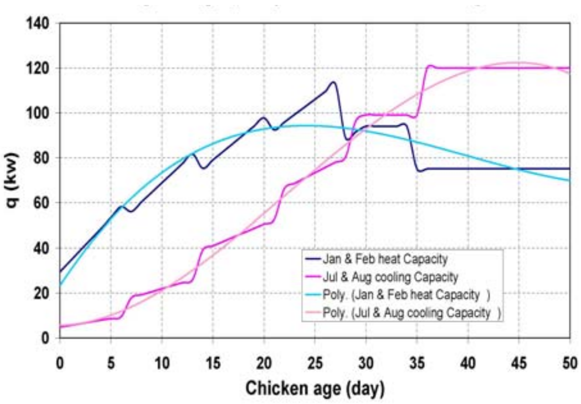

Fig. 10. Heating/cooling power as function of chicken age

Fig.10 shows that the required heating and cooling powers are 112 kW and 120 kW, respectively. The estimated total annual heating demand is 223 MWh while the corresponding cooling demand is 33 MWh. It was assumed that 10 h of cooling and 24 hours of heating are required per a day during summer and winter, respectively. The 5 cycles/year a 55 days means that the hangar is occupied by chicken 75% of the year.

System Design and Simulated Operation

The EED (Earth Energy Design) model [EED] was used in pre-designing required borehole system to meet to estimated heating/cooling load at given conditions.

Borehole System

- Number of boreholes: 10
- Borehole Diameter: 0.11 m
- Borehole Depth: 120 m
- Drilling Configuration: open rectangle (3 x 4)
- Borehole Spacing: 6 m.
- Borehole installation: Polyethylene U-pipe
- Fluid flow rate: 0.5 10^{-3} m^3/s, borehole.

To keep the borehole temperature at steady state between the years extracted and injected heat from/to the ground were balanced by charging solar heat during the summer.

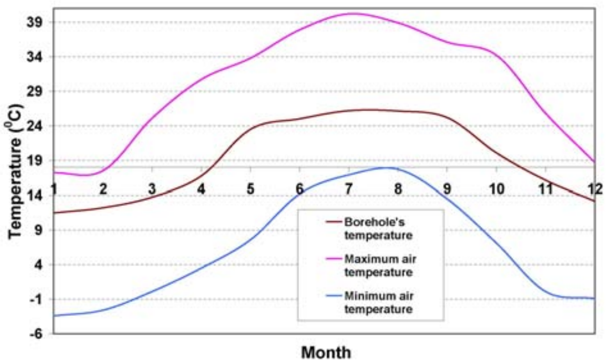

Fig. 11. Relevant temperatures for performed calculations

Solar Collector

The required solar collector area was determined without considering heat yield from ground by:

$$A = \frac{Q_h \cdot (1 - \frac{1}{COP_h}) - Q_c \cdot (1 + \frac{1}{COPc})}{\eta \cdot \sigma}$$

Where;

Q_h	Heating demand (MWh)
COP_h	Coefficient of performance for heating (in this case =5)
Q_c	Cooling demand (MWh)
COP_c	Coefficient of performance for free cooling (in this case =50)
σ	Yearly sun yield (in this case σ=1.973 MWh/m^2)
η	Solar collector efficiency (in this case η=0.86).

In this case, the required solar collector area is 85 m^2. The solar heat is directly used when needed while the rest of the heat is stored until later (Fig.12).

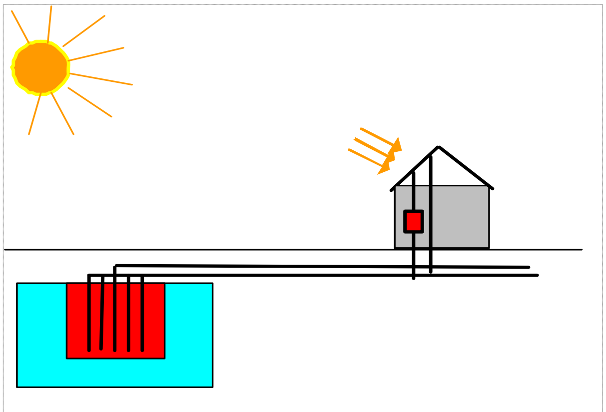

Fig. 12. Principle outline of solar heated storage system

Heat and Cold Distribution

Heating and cooling of the hangar are distributed by floor heating/cooling (UFH) and wall heating/cooling, see Fig.13. Since heat conduction through the ceiling represents ~25% of heating load, by use (UFH) air temperature close to the ceiling is reduced about 8°C lower comparing with normal heat distribution (Fig.13), that means heating load can be reduced 8%.

Floor heating means that warm water is circulated through special pipes in the floor, which effectively turns it in to a large radiator. Normally, such systems are used for low temperature heat distribution (30-35°C) though also warmer water can be used.

Under Floor Heating has also many advantages for this chicken house application:

1. Same comfort is obtained with about 8^{o}C lower air temperature
2. Reduced heat loss through windows, ceiling, walls, and ventilation
3. Reduced difference between heat source distribution temperature
4. Unobtrusive, safe and quiet and virtually maintenance free system
5. Simple to install
6. UHF keep the wood chips dry i.e. reduction of diseases and infections.
7. UHF heats the space from the chicken level, i.e. the highest temperature in the house will be at the chicken level.

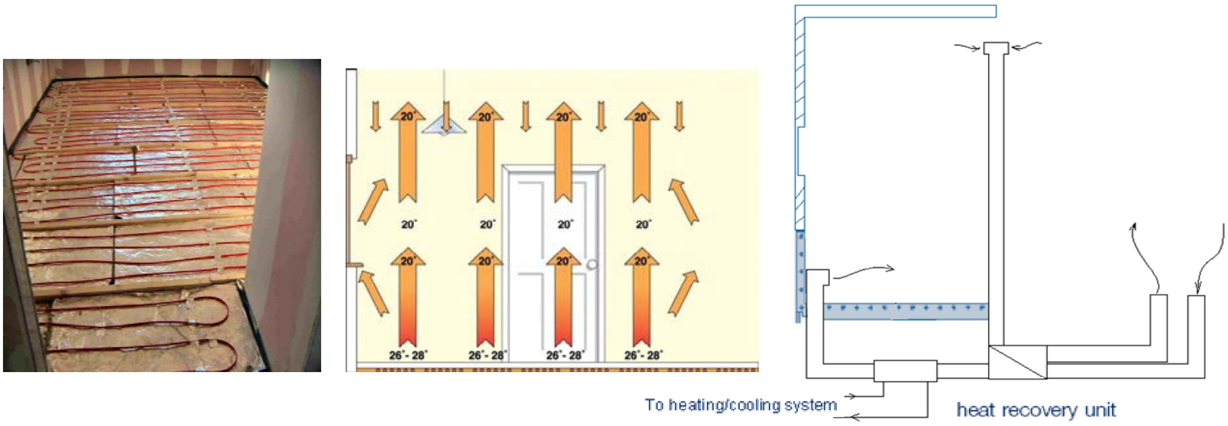

Fig. 13. Floor and wall heating/cooling distribution

Ventilation

Since the ventilation rate is relatively high (ventilation rate 20 m^3/m^2,h), the ventilation load represents 20-35% of the cooling demand during summer and about 60-70% of heating during the winter. Therefore, these heat losses are reduced by mechanically balanced ventilation using heat recovery, as shown in Fig.13. The gain was estimated assuming 20 ^{0}C air temperature at the ceiling and a heat recovery ε =80%. After such heat recovery the inlet air temperature during the coldest month is 15.3 ^{0}C instead of -3.4 ^{0}C.

Since heat distribution starts from the floor the lowest air temperature in the hangar is at the ceiling, while the opposite situation occurs during the summer. Therefore, to reduce ventilation load the ventilation system absorbs the air from ceiling level and provides with fresh air at chicken level Fig.13.

Operation

During the wintertime Fig.14-A, water is pumped from the borehole through the solar collector to increase its temperature. The temperature increase which is only 0.8 ^{0}C during the winter is considerably greater during the summer. The heat pump cools the water before it is again pumped through the borehole, where it will be warmed up. The extracted heat is emitted into the hangar. Fig.11 shows the temperature of extracted water from borehole.

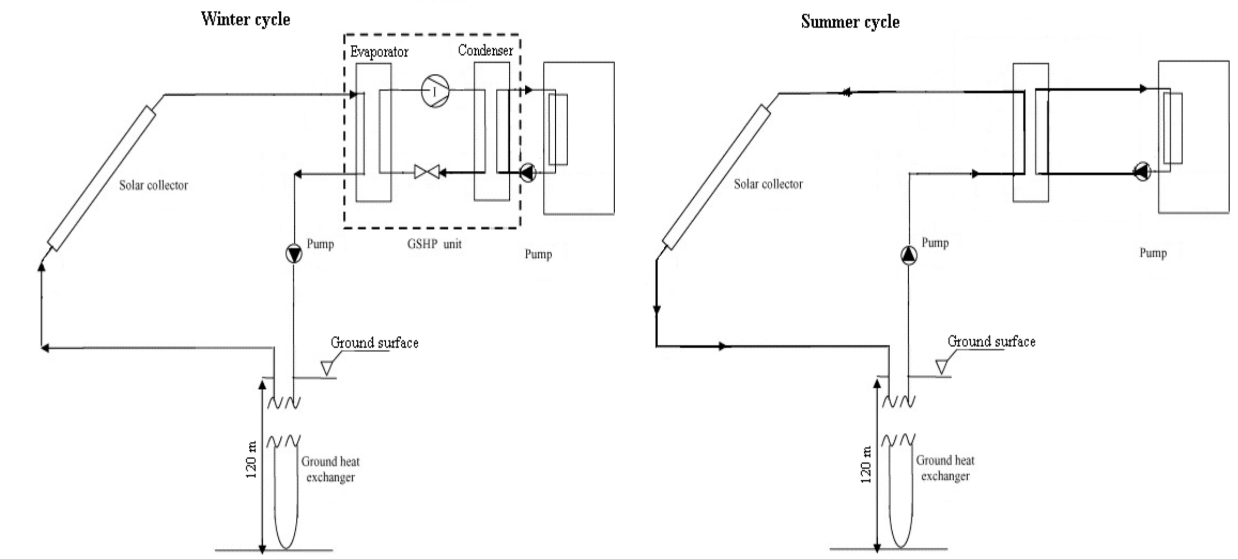

Fig. 14. Schematic of the solar coupled to ground source heat pump system.

During summertime Fig.14-B, the ground temperature is cold enough for free cooling, so the water is pumped directly to the heat exchanger. Due to the heat exchange with indoor air, the water temperature will increase. After the heat exchanger, water passes though the solar collector and back to the borehole. Then, its temperature will decrease before pumped back to the hangar.

Conclusions

Based on data for a specific chicken farm in Syria the heating cooling demand of a typical farm was estimated. A borehole system that meets these demands was designed and its cost was estimated. By assuming that such systems were used for chicken farms all over Syria its total potential was estimated.

1. A typical average size chicken house in Syria requires 90 MWh of heating and 13.3 MWh of cooling. Required heating and cooling powers are 112 kW and 120 kW, respectively. See Table 3.

Table 3 Heating and cooling demand for chicken farms in Syria.

Typical farm size Floor area 200 m^2				Totally for 13000 farms Floor area 2,6 Mm^2		
Meat production ton/year	Heating Energy MWh/year	Cooling Energy MWh/year		Total energy for heating GWh/y	Total energy for cooling GWh/y	Total Energy GWh/year
13	90	13.2		1170	172	1342

2. A borehole system of ten boreholes, drilled to a depth of 120 m as an open rectangle 3 x 4, meets this demand if combined with 85 m^2 low temperature solar collector. The boreholes supply free cooling during the summer.
3. The maximum fluid temperature delivered from the boreholes is 27^oC in the summer while the minimum mean fluid temperature is 11^oC during the winter.
4. The floor heating system decreases the heating demand by 8%. Heat recovery on ventilation air increases the inlet air temperature during coldest month to 15.3 ^0C instead of -3.4 ^0C, i.e. ventilation load will be decreased approximately 62% during coldest month in a year. This means that the heating power can be decreased ~40% and the heat demand by ~48%
5. The electricity consumption of a GSHP is considerably lower than that of an ASHP.
6. Table 4 shows a comparison of operation costs between the conventional (coal furnace), ASHP, and suggested GSHP heating/cooling system. COP_h and COP_c for the ASHP are 4 and 3.3, respectively, while the corresponding values for GSHP are 5 and 50.

Table 4. Comparison between different heating/cooling systems.

	Coal furnace		ASHP		GSHP	
	Heating	cooling	Heating	cooling	Heating	cooling
	90	13.2	90	13.2	90	13.2
Consumption	13 ton coal	-	22.5 MWh	4 MWh	9.36 MWh	0.25 MWh
Cost (S.P)	100000	-	67000	12000	28000	750

7. The climate conditions in Syria are favorable for seasonal heat storage, which means that there is a great potential for such systems in space heating/cooling of buildings in Syria.
8. Solar energy is more suitable in Syria than in most of Europe, which means that there is a great potential to utilize diurnally and seasonally stored solar heat.
9. By implementing suggested system in all Syrian chicken farms, the annual oil consumption would decrease ~0.72 Mbbl/year (see Fig.15), i.e. 72 M$ at current oil price.
10. The estimated installation cost of borehole system for one typical chicken farm is $15000, indicating a payback-time of about 2.7 years.

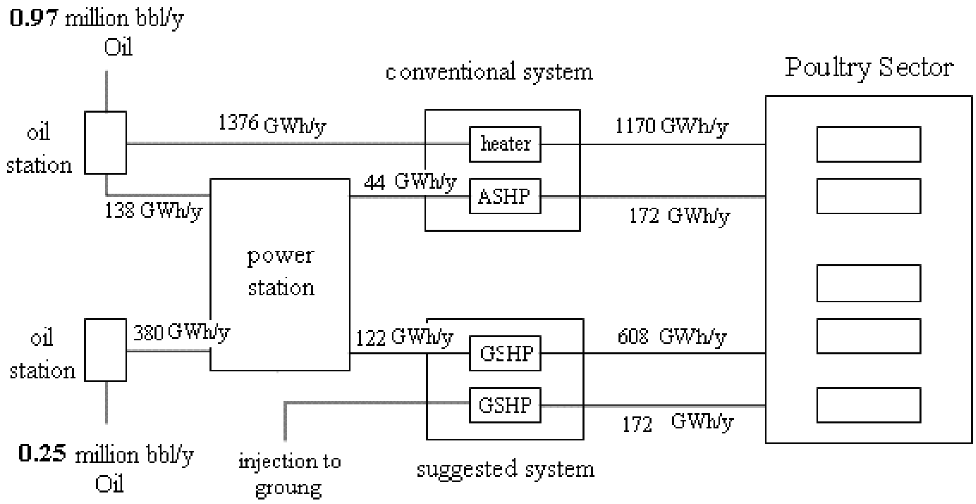

Fig. 15. Comparison between conventional and suggested system

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