Some researches in the field of using renewable energy on heating houses

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Abstract: Heating houses with the help of renewable energy sources is a very important object for studies in our days. The focus of study is a residence situated in the Sânpetru commune, at about 10 km distance from the city of Brasov. The earth was chosen as a heat source in the form of an exchange field made up of 4 horizontal serpentines buried 1.30-1.50m deep and the total length is 390m. The distance between the serpentines varies from 0.30m to 0.80 m. Laboratory analyses have determined the water content, the granularity, the porosity and the mineralogical nature of the ground. An analysis has been made of the trend of the coefficient of performance (COP), the thermal energy that was extracted from the ground, and the thermal energy produced by the pump

Key words: Heat and Mass Transfer, Heat pump, soil, coefficient of performance, thermal conductivity

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1. Introduction

99.5% of the earth's crust thermal energy derives from the sun and 0.5% from internal sources - radioactivity and internal pressure. Internal heat makes the geothermal gradient (temperature increase by one degree) to have an average of 33 meters, meaning 3ºC/100 m (geothermal gradient) up to a depth of about 2000 meters, after which the temperature has an exponential rise towards 3000-5000ºC at the nucleus. The average loss of internal heat (geothermal flux = the rock's thermal conductivity multiplied by the geothermal gradient) is 1, 25·10-6 cal/cm2/s in regards to which there are positive (hot-spotsin volcanic areas) or negative anomalies (for example from the oceanic trench).

The heat received from the sun varies according to latitude and season. Daily variations manifest themselves in the crust up to a depth of 75 cm and seasonal ones up to a depth of 10-20 m. These depths mark the balance area between the thermal radiation from the external source and the internal one and correspond to a constant temperature zone. Below these depths, the temperature is changing according only to the thermal gradient with values between 30 and 35 meters.

Climatic conditions grant Romania renewable energy sources in the medium and long term (solar energy, wind power, hydro energy, biomass and geothermal energy). Of the heat pumps that use geothermal energy, soil-water pumps are the most widespread at the moment, an estimation isover 1.5 million in the whole world.

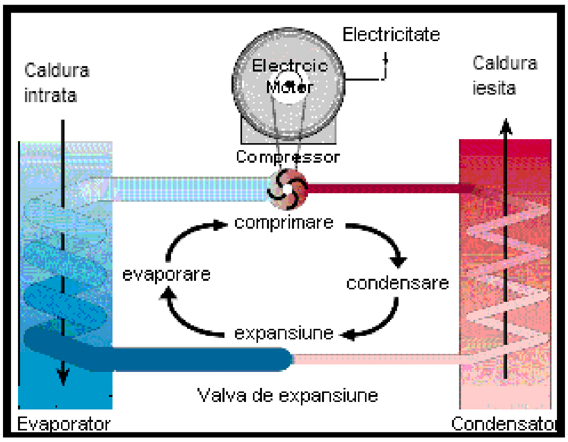

Fig.1 Heat pump (closed cycle) with mechanical vapor compression -principle

A quick survey of the development of these systems starts with a Swiss patent issued in 1912 to Heinrich Zoellythat makes a reference to a soil-water heat pump [2].

Between WW1 and WW2 this system was introduced in the United States. After the war their development continues in parallel to laboratory investigations and surveillance of the existing systems. Ingersoll and others [7] lay the theoretical groundwork for the research to follow. Interest for these systems was in declinein the 6th and 7th decades due to problems related to technological aspects, affected soil , installation undersizing [11] etc.

The 70's petrol crisis brought back attention to renewable energy sources. Research onheat pump systems had resumed with increased care to protect the soil by improving the system and soil space filling techniques. Agent losses are reduced substantially by the introduction of high density polyethylene pipes and connecting them to the heat source. The installations undersizing problems forced the introduction of new calculus algorithms [3] and their implementation on computers.

Commercial heat pump based systems become common again in the United States and in the Western Europe they are increasing, being led by Switzerland and the Scandinavian countries. The commercial aspect has forced putting research effort into computer simulation programs for cost reduction. Consequences over the affected terrain are studied with high priority for the system's long term behavior and from the ecological point of view. „In situ" research, especially in the case of commercial buildings reduces the degree of uncertainty and can establish a resizing much closer to the real needs; [1, 4, 5]. In some cases the cost difference from the direct analysis of the terrain can be as much asten's of thousands of dollars [13].

2. Geological context

The area that Brasov occupies is formed of two distinct parts: the ŢăriiBârsei depression and the orogen mass in which this basin is carved. This structure's evolution implies two processes: the basin's sinking and then it's filling with Neozoic sediments.

The orogen is represented by the most internal units of the Carpathians bend area (Ciucaş, Piatra Mare, Postăvarul, Bucegi, and Piatra Craiului mountains). From a geotectonic point of view these units are situated in the Crystalline – Mesozoic zone and are formed of shales, triassic, jurassic (particularly carbonated) and cretacic deposits, calcareous and detritus.

The forming of these massives was followed by the basin's sinking and it's filling with Neozoic-aged lacustrian sediments.

In the Quaternary, after the lake waters' receding from the Brasov region, the forming of piedmonts takes place: theSăcele piedmont, formed of the dejection cones of the Tărlung and Timiş rivers that have united, and the generator rivers were forced to deviate sideways towards lowest quotas; the Brasov's piedmont – formed of torrential waters and of smaller streams.

The forehead of the piedmonts is followed by large relief formations, „fields" or other rivers' terraces. The fields, like Măieruşului Field, Arcuşului Field, de la Reci Field, Bîrsei Field, Stupinilor Field are lacustrine plains joined by swamps, slops and deserted meanders. A lot of them have lost their initial state by being put into the agricultural circuit after draining.

3. Theoretical premises

Heat flux (q) from the soil particle to another or through soil pore fluids is:

$$q = -\lambda \cdot \frac{\vartheta T}{\vartheta x} \qquad (1)$$

where: T - temperature
x – distance
λ – thermal conductivity of the soil;

The negative sign indicates that the temperature decreases in the direction of increasing the distance.

Conduction through cylinders (heat pump case) is, and the length denoted as:

$$T_1 - T_2 = \frac{q}{2 \cdot \pi \cdot \lambda \cdot L} \cdot \ln \frac{R_2}{R_1} \qquad (2)$$

where: λ –thermal conductivity of pipe's material;
T_1, T_2 – temperature of internal and of the external surface of the pipe;
R_1, R_2 - internal and the external radiuses of the pipe;
L – pipe's length.

The amount of heat (Q) transferred in time t on the cross-sectional surface area A with a L thickness is:

$$\Delta Q = \lambda \cdot t \cdot \Delta T \cdot \frac{A}{L}$$

(3)

Johansen's model (1975)

$$\lambda_{unsat} = \left(\lambda_{sat} - \lambda_{dry}\right) \cdot \lambda_e + \lambda_{dry} \qquad (4)$$

where:

- λ_{sat}- thermal conductivity of saturated soils
- λ_{dry}- thermal conductivity of dry soils
- λ_e= 0.7 logSr+1 for coarse-textured soils
- λ_e= logSr+1 for fine-textured soils
- $\lambda_{sat} = \lambda_s^{(1-n)} \cdot \lambda_w^n$

(5)

where:

- □$_s$- thermal conductivity of soil; from the quartz content of the total solids content (q) and thermal conductivities of quartz (λ_q = 7.7 W m^{-1} K^{-1}) and other minerals (λ_o):
- $\lambda_s = \lambda_{qg} \cdot \lambda_o^{1-q}$ (6)

where:
λ_o was taken as 2.0 W m^{-1} K^{-1} for soils with q > 0.2, and 3.0 W m^{-1} K^{-1} for soils with q ≤ 0.2.
λ_w- thermal conductivity of water
n – soil porosity
λ_{dry}= 0.039 n22±25% for crushed particles;
Mean values:

λ_{sand} 7º=1.8 J/sec/m/ºC
λ_{sand} 10º=1.94 J/sec/m/ºC
λ_{clay} 7-10º=1.2 J/sec/m/ºC
λ_{water}=0.605 J/sec/m/ºC

Geometric mean method - Sass et al. (1971) and Woodside and Messmer (1961):

$$\lambda_s = \prod_{j=1}^{z} \lambda_{mj}^{xj} \quad \text{with} \quad \sum_{j=1}^{z} x_j = 1 \qquad (7)$$

where Π represents the product of the thermal conductivity of the minerals with λ_m conductivity each, raised to the power of their volumetric proportion x, and the sum of the volumetric proportion of the minerals is equal to 1. The subscript j refers to the j-th mineral, there being z minerals altogether. The quotation gives the best results when the thermal conductivity of each mineral does not differby more than one order of magnitude.
Typical range of thermal conductivities is shown in following tables:

Table 1. Thermal conductivity of solid particles of some minerals [6]

Mineral	□(W/m°C)
Amphibole	3,46
Chlorite	5,15
Feldspar	2,25
Olivine	4,57
Plagioclase (labradorite)	1,53
Quartz	7,69
Calcite	3,59
Dolomite	5,51
Mica	2,03
Plagioclase	1,84
Pyroxene	4,52

Table 2. Average thermal conductivity of rocks (various sources)

Rock	R (kg/m3)	□$_s$ (W/m°C)
Basalt	2.90	1.7
Diabase	2.98	2.3
Dolostone	2.90	3.8
Gneiss	2.75	2.6
Granite	2.75	2.5
Limestone	2.70	2.5
Marble	2.80	3.2
Quartzite	2.65	5.0
Sandstone	2.80	3.0
Schist	2.65	<1.5
Shale	2.65	2.0
Syenite	2.80	2.0

4. Case Study, Sânpetru, Braşov County

4.1 Existing situation

The object of study is a residence situated in the Sânpetru commune area, on the Renaşterii Street, nr.30, at about 10 km distance from the city of Brasov.
The earth was chosen as a heat source in the form of an exchange field made up of 4 horizontal serpentines buried 1,30-1,50m deep. Three of the four serpentines are 100 meters long, and one is 90m. The distance between the serpentines varies from 0.30m to 0.80 m.
For investigating the terrain characteristics, two drillings were made, one inside the capture field and another outside, as a blank test. The terrain samples that have been analyzed were from the following depths: 0.50m-0.80m, 1.00-1.30m, 1.60-1.80m on both drillings. The goal of the laboratory analyses was to determine the humidity (even though the obtained data was punctual in this instance), the granularity (the percentage distribution of the solid particles according to their size), the porosity and the mineralogical nature.

4.2 Results of the field investigations

The granulometric analyses have been made according to the Romanian standards, using the sedimentation method. The result was that the terrain is mostly clayey and has a high degree of non-uniformity which also givesit a reduced porosity. It is important to underline this fact because a reduce porosity, 35 to 40% in our case, givesthe terrain a superior thermal conductivity.
The volumetric water content, even though it was only determined with this sampling, is also good25-28% which means the terrain is classified as humid.

From a mineralogical point of view, quartz prevail with subordinate clay minerals in the following order: illite, montmorillonite and caolinite, which leads to the conclusion that a certain degree of alteration exists. The mineral's alteration degree suggests that the superficial deposits are at an incipient stage, intermediary at the most, according to the Jackson classification [11]. This conclusion is backed by the following arguments:

- the massive presence of finite fraction quartz, under 2μm;

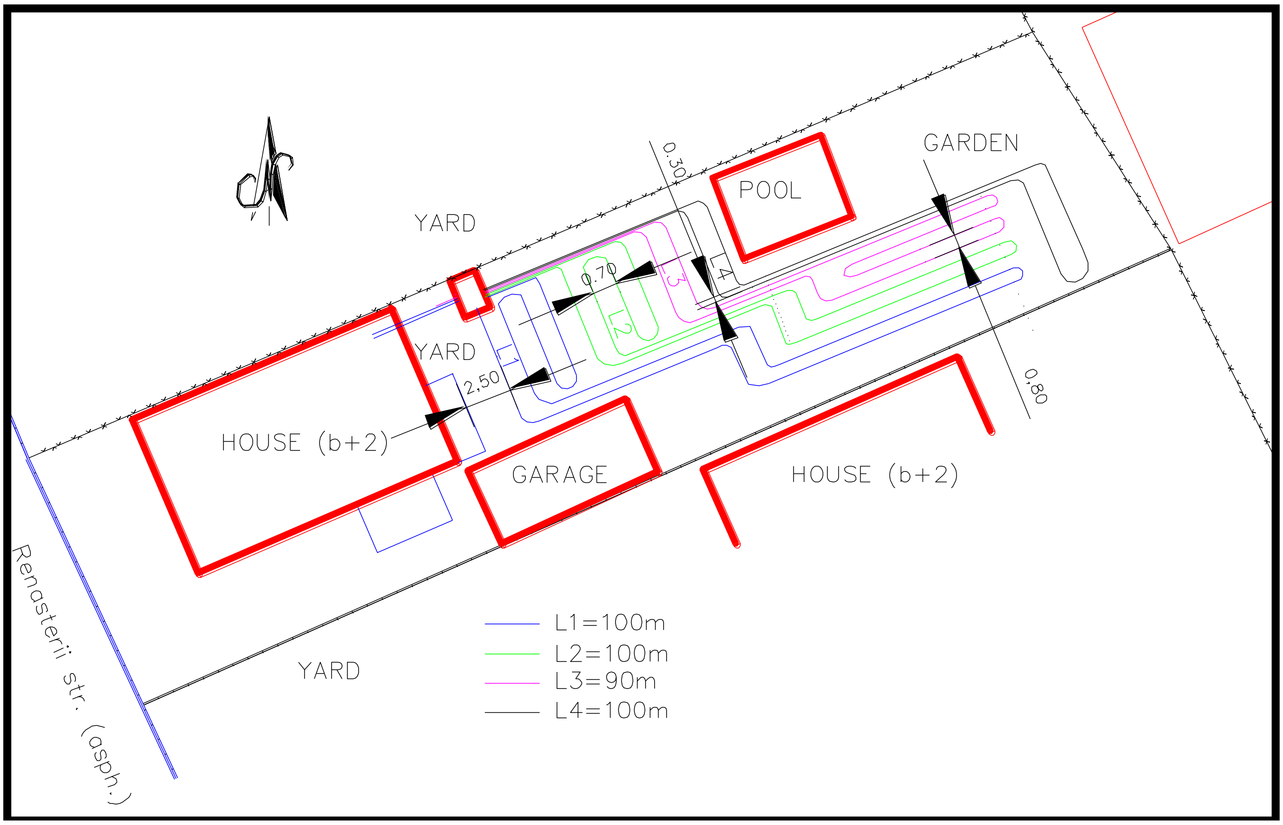

Fig. 2 Site plan

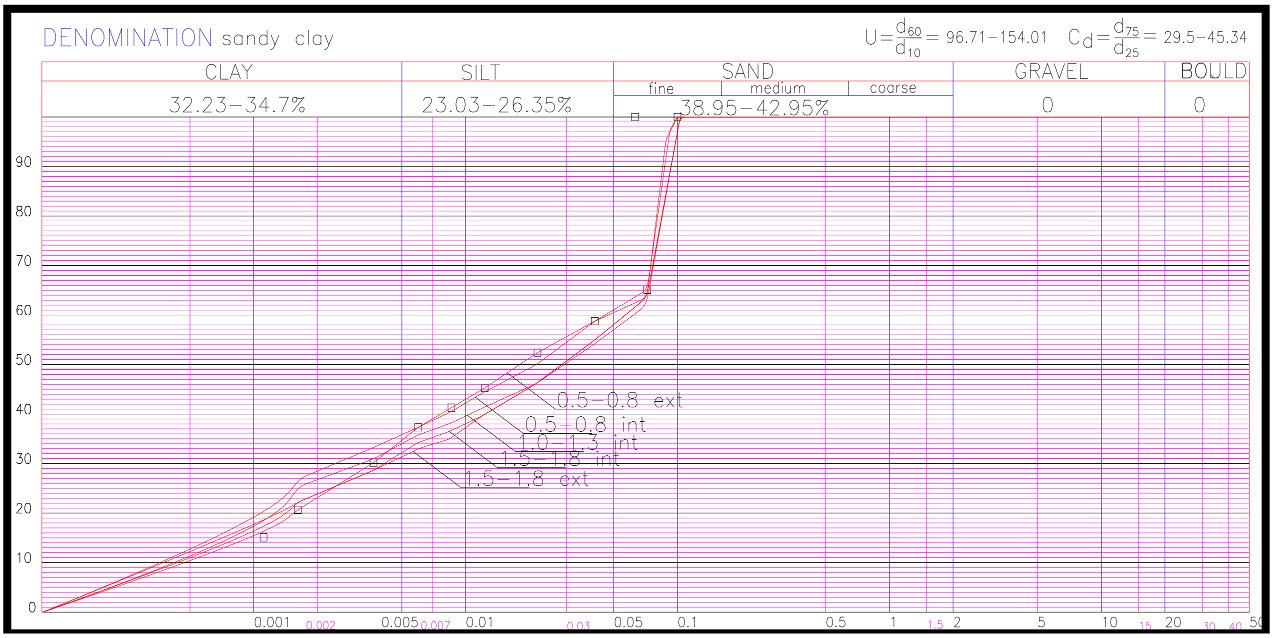

Fig. 3 Granulometric curves at different depths at interior of field exchange (int) and outside of the field (ext).

- relatively small quantities of clay minerals compared to the micas
- the relative prevalence of illite compared to other clay minerals

5. The heat pump's characteristics and the results of the installation monitoring

The heat pump's building has three levels, is constructed of masonry, GVP bricks with concrete floors.

The heat pump is type ViessmanVitocal 300 BWC 106 CD 70 6, 4 Kw sized to cover the necessary heat of the radiant floor (-5 kW), at the normal temperature of 40IºC

The total energy measured by the owner, who is also one of the authors of the present article, over a period of about 5 months between November 3rd 2008 and April 5th 2009 was of 6531 Kwh. In the this time consumed electrical energy was 2212 Kw r, that gives a coefficient of performance COP=2,901.

Table 3 coefficient of performance COP evolution on first 5 month of work

Month	COP
November 2008	4.05
December 2008	3.62
January 2009	3.24
February 2009	3,05
Mars 2009	2.92
Average	3.376

On the first 8 days of working, when an average outside temperature of 5ºC was recorded:

- $T_{\text{thermal energy from soil}}$ =229 Kwh
- $Q_{\text{electrical energy}}$ = 51.1 Kwh

It results: $COP = \frac{229}{51.1} = 4,481$

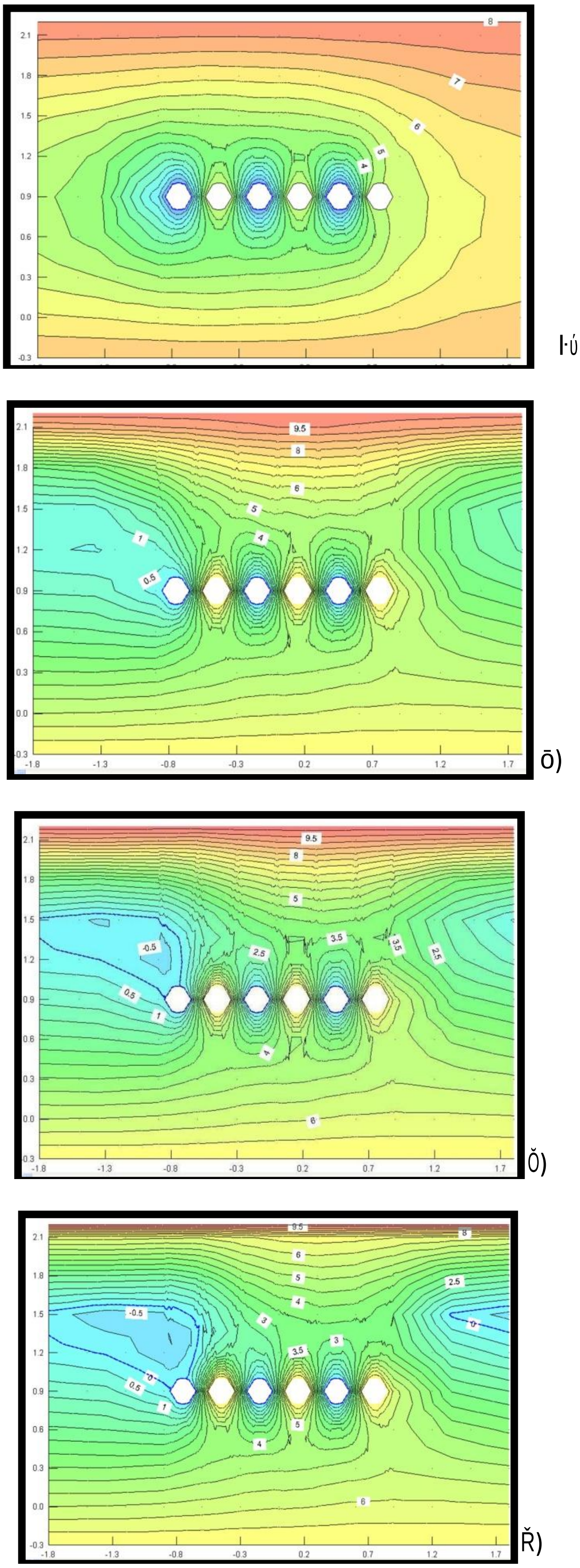

Fig. 4 Ground temperature evolution at different times: a) initial, b) 2 years, c) 4 years, d) 5 years

A computer simulation of 5 years of system's functioning shows that the soil loses itsthermal energy. The model was built with meteorological data for one year repeated identically. The most disadvantageous segment was chosen, the one wherethe distance between two pipes is 30 cm (Figure 2). There are some limits of the model, as follows:

- The summer season of transferring heat to the ground was neglected
- Reciprocal influence of pipes was neglected; boundary conditions on pipe's wall are functions of refrigerant liquid;
- Ground temperature at 3 meters depth is a linear cyclic function between 7 and 3ºC, on each 6 months.
- The seasonal variability of ground's water content was neglected;
- Thermal conductivity of pipes was neglected;

6. Conclusions

The average coefficient of performance from 3rd of November to 5th of April was COP=2,901.

On the first 8 days of functioning the coefficient of performance was COP=4,481. Thermal energy produced by the pump was 229 Kwh.

The diminishing trend of COP overtime isclear. These facts were confirmed by numerical modelling in transitory regime overa period of 5 years.

In future the system will be monitored also in the ground. Sensors for ground temperature checks will be placed at different depths and others for the measuring of water content.

References:

[1] Austin, W., C. Yavuzturk, and J.D. Spitler. 2000. Development of an in-situ system for measuring ground thermal properties.*ASHRAE Transactions* 106(1):365-379.

[2] Ball, D.A., R.D. Fischer, and D.L. Hodgett. 1983. Design methods for ground-source heat pumps. *ASHRAE Transactions* 89(2):416-440.

[3] Bose, J.E., J.D. Parker, and F.C. McQuiston. 1985. *Design/Data Manual for Closed-Loop Ground-Coupled Heat PumpSystems*. Atlanta: ASHRAE.

[4] Eklöf, C., and S. Gehlin. 1996. TED—*A mobile equipment for thermal response test.* Master of Science thesis, 1996:198E Luleå University of Technology, Sweden.

[5] Gehlin, S., and J.D. Spitler. 2003. Thermal response test for BTES applications—State of the art 2001. *Proceedings of Futurestock 2003 -- 9th International Conference on Thermal Energy Storage,* Warsaw, Poland, September 1-4, 2003, pp. 381-387. VOLUME 11, NUMBER 2, APRIL 2005 167

[6] Horai, K.I. 1971. Thermal conductivity of rock-forming minerals.*Journal of Geophysical Research*, 76(5): 1278–1308

[7] Ingersoll, L.R., et al. 1951. Theory of earth heat exchangers for the heat pump. *ASHVE Transactions* 57:167-188

[8] Johansen, O. 1975. *Thermal conductivity of soils*. Ph.D. thesis,University of Trondheim, Trondheim, Norway. CRREL Draft English Translation 637, US Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Hanover, N.H.

[9] Krahn J. (2004), *Thermal Modeling with TEMP/W – An Engineering Methodology*, Geo-Slope International Ldt., Calgary, Alberta, Canada

[10] Kroeker, J.D. 1949. In a comment on the paper: Guernsey, E.W., P.L. Betz, and N.H. Skau. Earth as a heat source or storage medium for the heat pump. *ASHVE Transactions* 55:321-324. Kroeker's comments may be found on pp. 336-337)

[11] Weaver, Clays, Muds and Shale. Developements in Sedimentology 44, *Elsevier*.