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Energy efficiency analysis of district heating using geothermal fluids

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ABSTRACT

In the light of the imperative need to save fossil fuels, renewable energies must be increased, and, in the meantime, the efficiency in energy use has become a priority and an urgent goal.

In Italy, a considerable part of energy's consumption is due to houses's heating and methane is by far the most used fuel.

Therefore, the utilization of low temperature renewable sources should be recommended for these purposes, and, in particular, the use of geothermal resources that are widely available in Italy.

This paper will analyze the natural gas saving's amount for the nation-scale system in case of traditional gas-fired heating's replacement with geothermal district heating.

The measure of this saving is given by the parameter "R" called "energetic saving index".

Geothermal fluids are not homogeneously spread over the country and their characteristics may be quite different (hot water or steam), consequently, various cases are here considered according to the different available fluid types.

In this view, four different cases of utilization of thermal fluids for space heating are considered; two of them regard high enthalpy fluids available only in geological areas with very high geothermal anomaly, while the other two cases are about fluids from moderate to low energy content that can be found in large areas of the Italian territory, where low geothermal anomalies occur.

Obviously energy efficiency changes with the design parameters, and to compare the efficiency in different configurations is therefore proposed a standard criterion called index "R".

To complete the analysis we must take into account the energy required to make the components and to build the plant. In this way, the pay back period, in terms of energy, can be estimated. This is particularly useful to compare different technical solutions.

To conclude, also while working with renewable energy sources; plants' design and operation must always search for solutions with higher efficiency.

1.INTRODUCTION

To reduce the fossil fuel consumption it is necessary to increase the renewable energys' use and the efficiency of the processes involving energy. A remarkable share of energetic consumption is due to the houses' heating[1] . In Italy, methane is today the more used fossil fuel (75%) for this purpose. But methane is also the fuel used in power plants with higher efficiency[2] . In other words, burning methane, is today the easer "solution". But we must always bear in mind that this is an expensive and limited resource, not sustainable for a long time. The transport of methane is easy and produces low emissions if compared with other fuels, but, methane's use to heat rooms at 20 C° is a huge wasting under an energetic point of view.

To increase the energy efficiency of the country it will be logical to use thermal sources at lower temperature for civil heating, and in detail, where available, geothermal resources.

This work wants to analyze the amount of saving of natural gas by traditional methane heating's substitution with plants working with geothermal fluids. These fluids are not spread homogeneously in the country, that's why we analyze several alternatives in function of the available fluid's characteristic (steam, hot water) and for each of them we analyze the amount of fossil fuels's saving. To measure the efficiency we utilize the value of a parameter "R" called "energy saving index" defined as the ratio of total fossil fuels saved (in methane's cubic meters) divided by the energy consumption for traditional heating with methane boilers (in methane's cubic meters) .

$$\mathbf{R} := \frac{\left[\left(\frac{\mathbf{Put}}{h\mathbf{b}}\right) - \left(\mathbf{Psc}\cdot\frac{\mathbf{C}}{h\mathbf{c}}\right) - \left(\frac{\mathbf{Pp}}{h\mathbf{c}\cdot h\mathbf{r}}\right)\right]}{\left(\frac{\mathbf{Put}}{h\mathbf{b}}\right)}$$

$$\mathbf{Put} := (\mathbf{Psc} - \mathbf{Pdis})\cdot(1 - \mathbf{cdt})$$

Where:

Put = thermal energy allowable by the end user

h**b**= boiler efficiency

h**c**= thermal energy at heat exchanger near geothermal resource

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[1] In Italy during 2005 the heating consumption has been about 33 Mtep. This value is equivalent to 15 % of the total energy consumption as described in: "Bilancio di sintesi dell'Energia in Italia per il 2005 Ministero Attivita' Produttive".

[2] The electric energy produced in Italy burning methane in combined cicle plants is about 40% of the total, with an energy efficiency up to 56%. The average efficiency of other plants is less than 40%.

C = electrical Mwh produced with 1 thermal Mwh using geothermal fluid for electrical production

h**c** =thermal cycle's efficiency used to replace electricity lost in geothermal electricity's production

Pp= electrical energy adsorbed by pumps

h**r**= reduction coefficient for loss in electrical network

Pdis = thermal energy lost in primary pipeline

cdt= coefficient for thermal loss in the distribution network

If the index approaches the value "1" it means that we reach the same goals reducing to zero the consumption of fossil fuels; for example if R reaches the value "0,9" we obtain the same thermal condition in the rooms using in the whole process only 10% of fossil fuels energy with a saving of 90%.

2.TYPE OF PLANTS ANALYZED

The plant model used for computing includes a heat exchanger located near the site of a primary geothermal fluid; where the heat's exchange with a secondary fluid takes place[3] . This secondary fluid, pressurized hot water, is then carried by two pipelines (outlet and inlet) to the distribution network.

3.MAIN ASPECTS THAT CAN AFFECT THE VALUE OF THE "R"ENERGY SAVING INDEX

Four main aspects can affect the value of the "R" energy saving index and they are:

1- The heat source used for thermal purposes could have rather been exploited for electricity's production; in this case the lost generation should be replaced by different sources (fossil fuels or others).

2-The amount of energy necessary for circulation pumps in the district heating circuit; once again, this energy has to be provided by other sources.

3-The difference between outlet and inlet temperature depends on the type of supplied domestic plant[4] and influences the amount of power required by the pumps, the diameter of the pipes[5] , as well as the amount of geothermal fluid shifted from electric power production[6] .

4-The distance between the geothermal fluid production area and the final users affects the heat losses, the power of the pumps, the diameter and length of the pipes.

Clearly the energy efficiency is related to the design parameters, and to compare the efficiency in different configurations is therefore proposed a criterion called index "R".

4.DESCRIPTION OF THE LOGICAL PROCESS FOLLOWED

In fig. 1 we have the exemplification of the analysis done for a geothermal fluid suitable for electric production, to evaluate the fossil fuel's saving. The number means energy expressed in term of methane equivalent consumption.

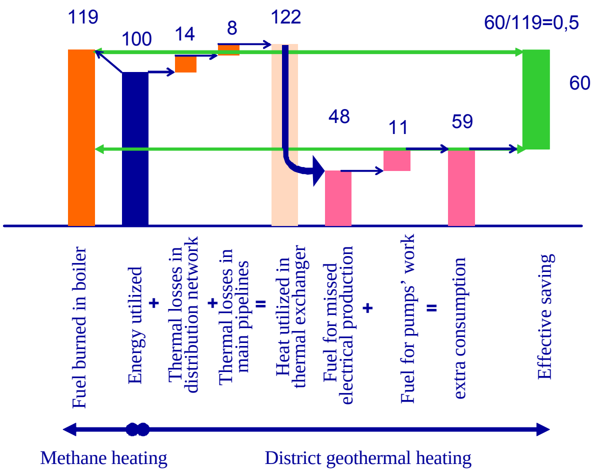

Figure 1. Exemplification of the analysis done to evaluate the fossil fuel's saving, in case of thermal utilization of a geothermal fluid suitable for electric production. The number means energy expressed in term of methane equivalent consumption

We suppose 100 the amount of thermal energy needed for heating. Using methane due to the burning efficiency we use 119. If we want to obtain the same 100 using a remote heating network at the starting point we must add the thermal losses all along the lines, we reach this way 122. If we use geothermal fluid to warm the secondary fluid, we must work out the loss of electric production due to the use of that geothermal fluid. We assess this amount 48 (we have different efficiency between geothermal and combined cycle plants). At this value we must add the energy consumption for pumping the secondary fluid, that expressed in "methane equivalent" is 11. Giving a value for the further energy consumption we obtain: 48 + 11 = 59. This value is the unique fossil fuel's consumption in the present case, therefore in this situation the fossil fuel' saving is 119-59 = 60, and a value of energy saving index R = 60/119 = 0,5. The situation analyzed shows that the

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[3] We only have analyzed the hypothesis of water vector; there are other solutions that here are not examined.

[4] The traditional plants in Italy need fluids with temperature of about 90°C.

[5] The thermal power transmitted is proportional to fluid flow rate by the difference of temperature between going and return. Increasing this temperature's difference we can reduce the flow rate and as a consequence the diameter of pipes or the pumps's power. Under this point of view a temperature's increase is useful, but on the other side we need primary fluids at higher temperature and of higher quality so increasing the loss for missed electric production

[6] Under a thermodynamic point of view the best utilization should be a mixed utilization, at first to produce electric energy, than a thermal utilization. But the thermal utilization has a load diagram that changes with the external temperature and the climatic characteristics of the place. Moreover at Italy's latitude the thermal charge is concentrated in few months. As a consequence if the availability of thermal source is constant, the frequent fluctuation of the thermal charge points out the problem of maintaining high the energy efficiency of the systems

utilization of geothermal fluids (in the illustrated condition) produces a methane's saving of 50% respect to the traditional use of the domestic methane burners.

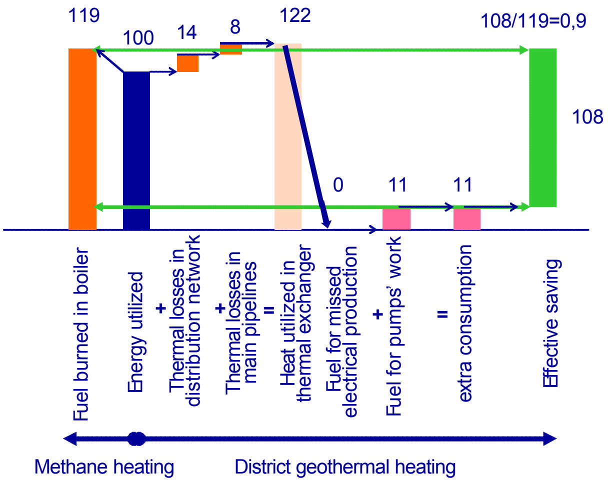

Figure 2. Exemplification of the analysis done to evaluate the fossil fuel's saving, in case of thermal utilization of a geothermal fluid non suitable for electric production. The number means energy expressed in term of methane equivalent consumption.

Fig 2 describes the exemplification of the analysis for a geothermal fluid non suitable for electric production.

The savings in this case are greater than in the previous example because there is not the amount of energy proportional to the missed production of electricity. The saving is 108, and this value comes from the difference between 119 (the energy burned in methane boilers) and the "methane equivalent energy", necessary for pumping the secondary fluids along the pipe line, equal to 11. We have in this situation an energy saving index R (108/119)=0,9. In other words using geothermal fluids in this case we will have a fossil fuel's saving of 90%.

We must bear in mind that the values here described are calculated, and valid, only in a specific case. They depend on the project and are function of the main parameters described above. To understand the laws that rule the changes in parameter R we have exanimate four more significant cases.

To complete the analysis of energetic savings, we have calculated the amount of energy used for construction. With this value we can calculate the pay back period, from an energetic point of view, which is to say how long it takes to make the energy savings compensate the energy used for the construction. This is helpful to compare several technical solutions[7] . The calculation doesn't concern the energetic expense for the construction of minerary works necessary for finding geothermal fluids (this is certainly lower to the equivalent necessary for methane's drawing out and transport).

4.CASES UNDER EXAMINATION

We have analyzed four situations to evaluate the variation of energy saving index R in function of the technical parameters before described (size of the plan, distance from source to utilization, difference of temperature between outlet and inlet of the secondary fluid, velocity of secondary fluids, fluid's withdrawal from electricity production). We have calculate furthermore, by changing the value of these parameters, the number of years needed to pay off, from an energetic point of view, the energy needed for construction with annual savings.

Situation 1

Town with 2000 residences and distance from source of 20 Km. Fluid available at temperature T= 180 ° C and a pressure P= 6 bar with an utilization of fluid's thermal energy only for heating without electrical production[8] .

Number of years with secondary fluid velocity of :
1m/sec (red line) 1,5 /sec (blue dotted) 2 m/sec (green dashed)
Town with 2000 residences and distance from source of 20 Km

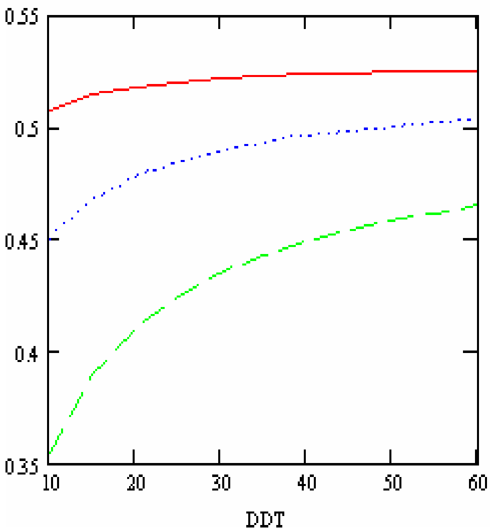

Figure 3. Comparison of energy saving index, in case of thermal utilization of a geothermal fluid suitable for electric production, versus the temperature's difference DDT (°C) between the vector fluid's inlet and outlet (case 1) .

In this case the available fluid allows rising the inlet's temperature with a pipelines' section's reduction and smaller losses of pumping. On the other side, however,

[7] This valuation needs the knowledge of the energetic consumption to build plants and of the energy consumption during construction and transport of the components. For this calculation we have utilized literature data (Gianni Riva: I bilanci energetici. In "La Termotecnica", Genn-Febbr. 1996) for primary energetic content of main row material (steel and thermal insulation) and hourly energetic amortization for the working machines used. These values are multiplied respectively for quantities installed and working time.

[8] We must underline that a thermal utilization produces a complete condensation of geothermal fluids with an amount available for reiniection of 100%. The traditional utilization for the electric production with evaporative cooling tower doesn't reach this value.

there is an energy electric's production's lack that must be compensated by other sources. This is the principal factor that produces, in this case, a value's fall of the energetic saving.

Number of years with secondary fluid velocity of :
1m/sec 1,5 /sec 2 m/sec
Town with 2000 residences and distance from source of 20 Km

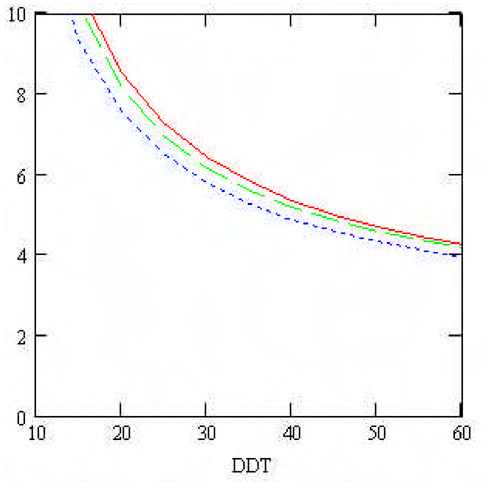

Figure 4. Comparison of number the years of energetic amortization, in case of thermal utilization of a geothermal fluid suitable for electric production, versus the temperature's difference DDT (°C) between the vector fluid's inlet and outlet (case 1) .

Energy saving index R with secondary fluid velocity of : 1m/sec 1,5 /sec 2 m/sec
Town with 2000 residences

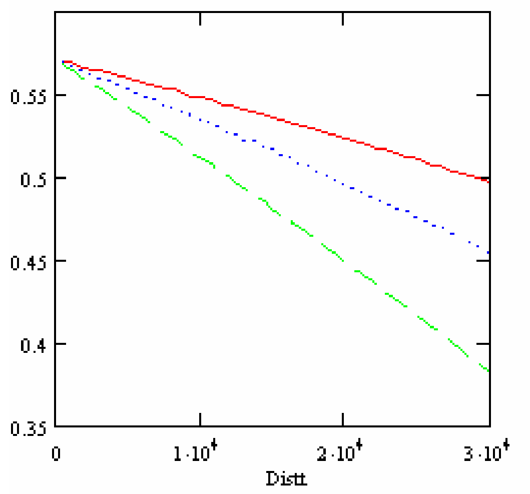

Figure 5. Comparison of energy saving index, in case of thermal utilization of a geothermal fluid suitable for electric production, versus the distance from source Distt in meter (case 1) .

To be kept in mind is that, without co-generation, it is better to raise the fluid vector's temperature; thus energy's saving increases (fig 3);besides, rising from 20 to 60°C the temperature's difference between the vector fluid's inlet and outlet circuits, the number of the years of energetic amortization is halved by8 to 4 (fig 4).

Energy saving index R with secondary fluid velocity of : 1m/sec 1,5 /sec 2 m/sec
Town with 2000 residences and distance from source of 20 Km

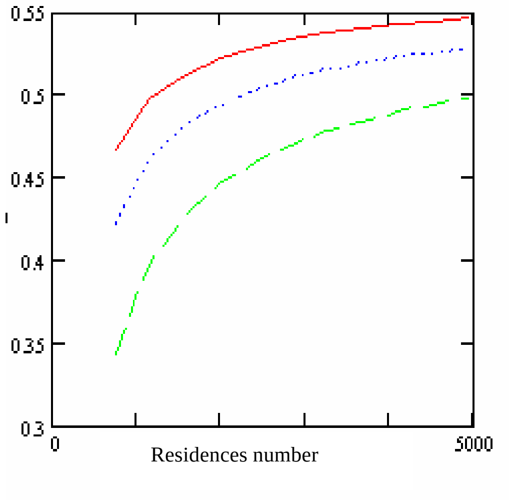

Figure 6. Comparison of energy saving index, in case of thermal utilization of a geothermal fluid suitable for electric production, versus the residences number (case 1) .

Energy saving index R with a pipe line length of :
20 Km 40 Km
Town with 2000 residences

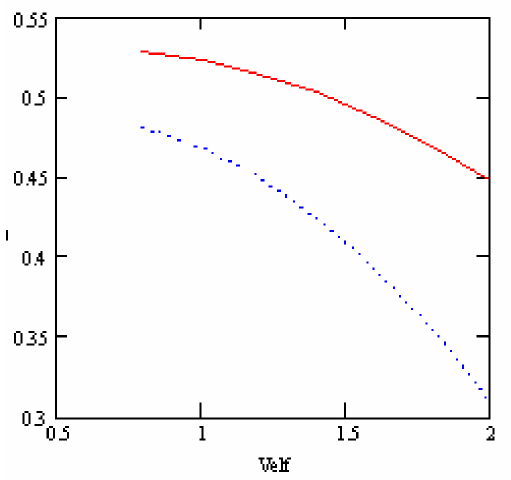

Figure 7. Comparison of energy saving index, in case of thermal utilization of a geothermal fluid suitable for electric production, versus the secondary fluid velocity (Velf) in m/sec at maximum charge (case 1) .

In this case particular technologies must be used to install underground pipelines, both for their thermic isolation and for the expansions's compensation's system. The technological research in this sector is really working in such direction, with the purpose to introduce on the market underground pipelines resistant to higher temperatures and, at the same time, with acceptable costs. Figs. 3, 4, 5, 6 and 7 show as the hydraulic sizing (expressed as the fluid's speed in conditions of maximum flow) can influence to not only the energetic efficiency but also the time the plant's energetic amortization; In fact, while increasing the pipelines' diameter, on one side the pumping's losses are reduced, but on the other side the thermal dispersions and the quantity of the materials to install increase, with consequent increase of energy requirement for their construction. Fig. 5 underlines how the energetic saving's parameter R changes according to the distance for an inhabited center of the indicate dimensions. The time of energetic amortization grows with the distance. In Fig. 6 we analyze the variation of R for a center with variable dimensions by 1000 to 5000 equivalent residences, with a line of transport of 20 km. With this variation of the users' number the years of energetic amortization pass from 8 to 4.

Situation 2

Town with 2000 residences and distance from source of 20 Km. Fluid available with a temperature T= 180°C and a pressure P=6 bar with a first fluid's utilization to produce mechanic energy to pump secondary fluid toward users and then a thermal utilization for heating.

Energy saving index R with secondary fluid velocity of :
1m/sec 1,5m/sec 2 m/sec
Town with 2000 residences

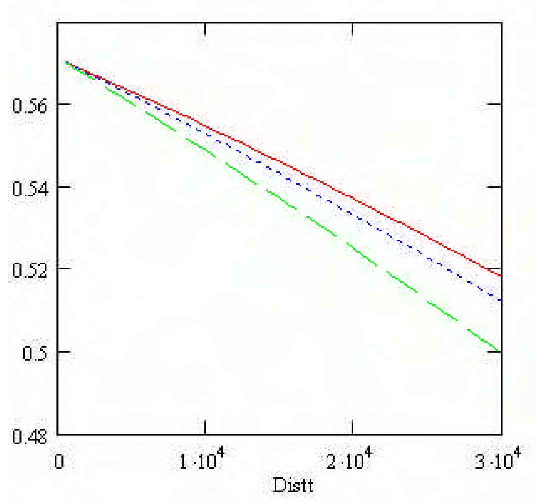

Figure 8. Comparison of energy saving index, in case of thermal utilization of a geothermal fluid suitable for electric production that produce mechanic energy to pump secondary fluid toward users, versus the distance from source (Distt) in meter (case 2) .

This case shows an energy efficiency's increase due to the self production of energy for pumping.The quantity of energy subtracted to the thermal energy for the remote heating is a small percentage that doesn't produce a lowering of the maximum temperature reachable by the secondary fluids (for the width of DDT here examined). We refer to another paper for a deeper analysis of co-generation's related problems, in this case we have supposed to use the geothermal fluid for producing the pumping energy, because this energy increases the same way as the thermal energy required for heating.This solution allows to set the pump directly in action with the available steam avoiding the use of electrical production plant that is always expensive.If we compare fig 8 representative of the situation n°2 with fig 5 describing situation n°1 we can notice that energy efficiency increases in the last case.This happens not only because the energy for pumping is directly produced by the steam but also because we can realize a different fluidodynamic project with higher speed that reduces the dimension of the pipe lines and consequently the thermal loss. Increasing the temperature's difference between outlet and inlet of the secondary fluid from 20 to 60 degrees, we have a considerable reduction of the energetic amortization time that, as described in case 1, is reduced from 8 to 4 years as described in fig 9.

Situation 3

Town with 1000 residences and distance from source of 1 Km. Fluid available water at 99 degrees of temperature.

In this analysis we study the possibility of using fluids with relative low energy content, not suitable for the electrical production, but their use for thermal purpose gives the maximum efficiency (fig 10). These kinds of fluids are widespread, hence the possibility of their utilization is wide also. For this plant we have supposed, as the previous cases, a return temperature of the secondary fluids of 70°C. This temperature is due to the technology used to build domestic heating systems working by fossil fuels (see note 4).

Number of years with secondary fluid velocity of :
1m/sec 1,5m/sec 2 m/sec
Town with 2000 residences and distance from source of 20 Km

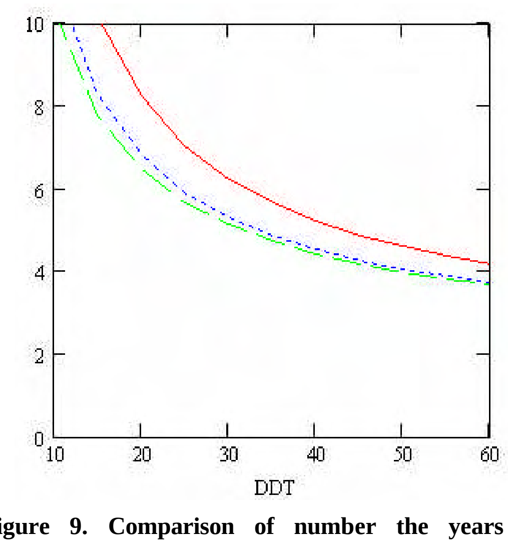

Figure 9. Comparison of number the years of energetic amortization, in case of thermal utilization of a geothermal fluid suitable for electric production that produce mechanic energy to pump secondary fluid toward users, versus the temperature's difference DDT (°C) between the vector fluid's inlet and outlet (case2) .

The value of 70°C is excessive for heating a place at 20°C but in this way it is possible to use smaller indoor heat exchangers and there's no limit at burning fossil fuels. In these situations the maximum difference of temperature for secondary fluids is less than (99-70) = 29°C. This requires a bigger pipe's diameter and more pumping energy. Nevertheless, as we don't have an electric energy's production's loss, the energy saving is higher and the amortization time is near 1 year.

Situation 4 Town with 1000 residences and distance from source of 1 Km. Fluid available water at 70°C of temperature.

Energy saving index R with secondary fluid velocity of :
1m/sec 1,5 /sec 2 m/sec
Town with 1000 residences and distance from source of 1 Km

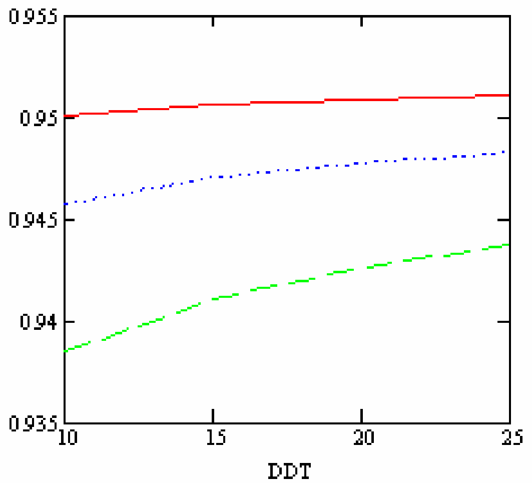

Figure 10. Comparison of energy saving index, in case of thermal utilization of a geothermal fluid non suitable for electric production, versus the temperature's difference DDT (°C) between the vector fluid's inlet and outlet (case 3)

With this starting temperature we obviously have a lower usable energetic content then in the previous case. On the other side the number of places where this resource is avalaible increases. The use for heating needs, in some traditional domestic plants, an increase in temperature on the inlet circuits, this may be realized with heat pump plants. These plants that use electric energy may increase the temperature and, the less is the temperature's difference asked, the less is the electric energy's consumption. It is possible this way to approach the previous case. Yet if we want to maximize the energy efficiency we must apply technological solutions for the domestic heating able to increase the heat exchange coefficients, so that the heating can work with secondary fluids at a temperature higher of 15- 20°C than the temperature of the space to be heated. The secondary fluid's return's temperature may be in this case nearly 40°C (with an indoor temperature of 20°C) with a difference of temperature between going and return greater than 20°C. In this situation the diagrams of fig 10 showed for "Situation 3" -for a difference of temperature of 20°C- is still reliable.

5.CONCLUSIONS

The need to reduce the fossil fuels' consumption forces toward energy efficiency. And this must be an urgent and priority goal.

In this point of view, for example, we have exanimate four different situations where it is possible to use geothermal fluids for domestic heating instead of fossil fuels. Two situations with high enthalpy fluids (which can be available only in geological situations characterized by a high thermal anomaly). Two situations with moderate or low enthalpy fluids which are available in many areas.

We have demonstrated that changing the project's choices we can have different values of energy efficiency, we have calculated a parameter said "R index" to measure and to compare the various solutions.

The fields where minerary investigation to find fluids suitable for the electrical production has been already done benefit of the certainty of having heat at high enthalpy. By the comparison of the examinated situations it is clear however that is more convenient to use geothermal fluids at low temperature for heating. Remote heating that uses those fluids allows energy saving up to 90% respect to methane.

For this reason if we want to save fossil fuels, and primary methane, it is important to stimulate investments for exploitation in fields not investigated by traditional activity that looks for fluids available for electrical production.

At last, we must underline that to increase the energy efficiency of a remote heating's system that uses geothermal fluids at low temperature and to reduce the investments necessary to build pipeline networks it is imperative to change the traditional construction's technology used today with low domestic heat exchange surfaces. We must think that to worm a domestic place at 20°C it is enough to have fluids with temperature a few greater than this value. On the contrary the current plants, born to use heat produced burning methane, gasoline, gpl etc, where high temperatures are reached, have small excange surfaces. These reduced surfaces are not efficient for geothermal fluids's use at low temperature. We must encourage the installation of plants able to use fluids with low temperature (35 - 45°C) as happens in plants using geothermal heat pumps.

REFERENCES

Gianni Riva 1996: I Bilanci energetici. La Termotecnica Genn-Febb 1996

Ministero Italiano Attivita' Produttive 2005: Bilancio di sintesi dell'Energia in Italia per il 2005

U.G.I 2006: Geothermal energy: Yesterday, today, tomorrow . Edizioni ETS

Lei Haiyan 2006: Simulation of district Heating in Tianjin,China. GRC, Transaction Vol. 30, 2006