HARNESSING SOLAR ENERGY FOR WINTER ROAD CLEARING ON HEAVILY LOADED EXPRESSWAYS

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1. Abstract

Express roads in the neighbourhood of the larger conurbations in Switzerland are already today very heavily loaded. Vehicle frequencies are climbing even further, so that an undisturbed traffic flow becomes vital. Very little is required under Winter conditions in particular to bring traffic to a standstill. In such a case the service vehicles of the road department are unable to access and treat the road surface. A system is needed therefore, which can keep the traffic lanes continually clear and safe. The SERSO-PLUS system, developed from the well-tried SERSO experimental installation (Solar Energy recuperation from Road surfaces – in German: **S**onnen-**E**nergie-**R**ückgewinnung aus **S**trassen-**O**berflächen) offers an environmentally acceptable solution.

A SERSO system collects from just beneath the road surface the excess heat from solar warming in Summer and stores it underground in a rock storage volume. The stored heat is then re-used in Winter to control the temperature of the surface. The surface temperature is stabilised just above 0°C, thus hindering ice formation and the freezing of compacted snow. In this way de-icing is assured and traffic interruptions to a large extent avoided. Experiences from the operation of SERSO justify this claim. In the climate of central Europe, it is in general possible to extract more heat from the roadbed in Summer than necessary for the following Winter. It has also been confirmed moreover, that SERSO operation brings a significant stabilisation of the road surface temperature throughout the year. This implies that, compared with the standard situation, the maximum temperatures are reduced in Summer and the minimum temperatures raised in Winter, resulting in an extension of the lifetime of the road's bituminous running surface.

A SERSO-PLUS installation consists essentially of a collector surface, whose extent corresponds to the traffic lanes, and additionally a variety of heat sources situated in the immediate neighbourhood. All elements of a SERSO-PLUS system must be so conceived as to allow the integration of their construction or installation into the work flow of a road surface replacement programme. The collector components will be installed together with the new roadway and then connected with the remainder of the system and operated outside this area.

The technical feasibility of SERSO-PLUS and some energy modelling results are shown. Also shown are the elements of the cost-benefit analysis, employed for establishing the global economics of the system, with an overview of the approach. The benefits considered include reductions of accident costs, of the costs of traffic jams, of maintenance work, of the use of material and equipment and finally the reduction of wear during the Summer leading to extended lifetime. On the other hand, additional and alternative costs are considered. The positive outcome of the economic study has led to a decision to install the system on a heavily loaded section of the Swiss motorway network, due for major renewal.

2. Introduction And Description Of The Task

Traffic density on the Swiss national motorway network is already high and is still increasing. Road users take the availability of the roads, even under bad weather conditions, for granted.

At peak traffic times in the conurbations in Winter, particularly in the early morning, the traffic density during periods of bad weather is so high that rapid access for the road maintenance vehicles is scarcely possible. If the traffic slows to stop-start crawl or becomes jammed under conditions of continuing snow fall, the onset of very difficult conditions, including direct ice formation or freezing of the snow layer, can arrive within minutes. The state of the road surface can only be rectified after the freeing of the jam and then with the expenditure of considerable time and resources. The political economic effects of a disturbance of this nature are considerable, especially those arising from the traffic jam itself.

Some additional mechanism is needed under such conditions to maintain the traffic lanes free of ice or snow, or at least to delay the onset of critical conditions until traffic conditions have normalised. Conventional automatic spraying of anti-freeze in critical stretches of road can be used. However, new, environmentally favourable methods must be sought. Amongst these the further development of the SERSO solar energy utilisation system can certainly be counted. The SERSO installation on the Därligen bypass on the A8 Express road was first put into trial operation in 1994.

3. Experience Gained With SERSO

Very positive experience has been collected over several years of operating the SERSO pilot installation, which is situated on a bridge previously notorious for the number of Winter accidents.

The SERSO system collects heat from the roadway, when it is warmed by the Sun in the Summer, and stores it in an underground rock storage volume. In Winter the stored energy is used for the temperature control of the road surface (see Fig. 1). A six year trial period has been completed and the system runs now in a normal operating mode. The essential experiences are now discussed.

Figure 1 – Winter operation of the SERSO pilot installation.

3.1 Energy

The system collects heat continuously from the bridge's roadbed in Summer and transmits it to the underground store, where the temperature rises to almost 20°C. In a typical Summer season approximately 140 MWh of heat energy will be stored. About a third of this quantity is lost subsequently from the store to the surroundings. The amount of energy, which can effectively be stored varies from year to year and is a function of, amongst other factors, the amount of energy in the store at the end of the Winter season: if the store is empty a large amount of energy can be stored; if it is still relatively full only a small amount can be stored (see Fig. 3).

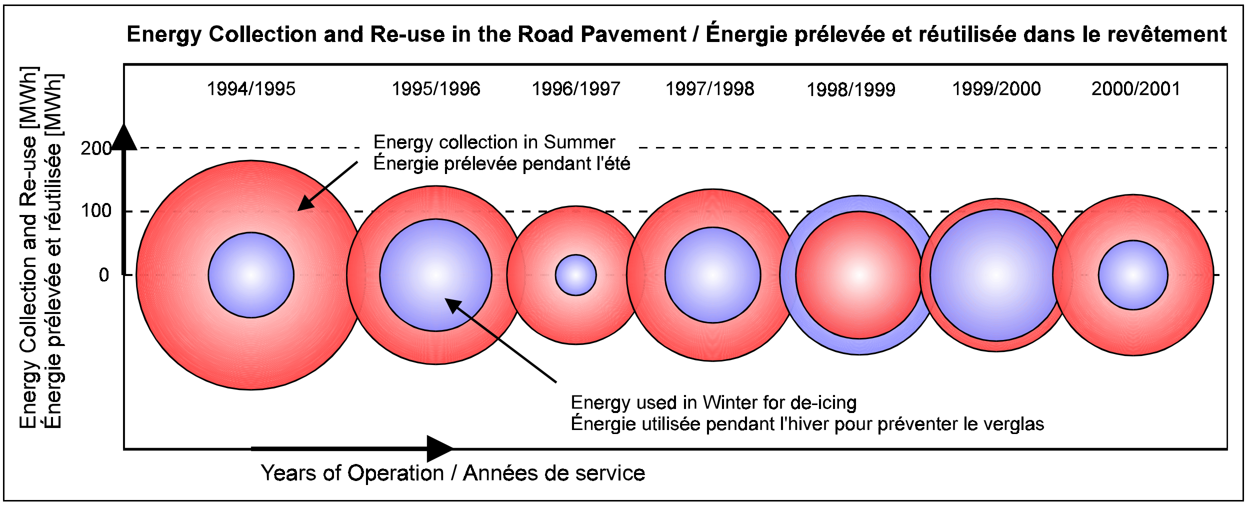

Figure 2 – Energy collected in Summer and re-use in Winter in the pavement collectors (from SERSO measurements)

In Winter the plant operates on demand. The delivery temperature of the heat transfer fluid is regulated according to ambient air temperature, lying generally in the range between 6° and 10°C. Ice formation is not possible under these conditions. The amount of energy demanded by the roadway varies strongly with the severity of the Winter from 30 MWh up to more than 100 MWh (see Fig. 2).

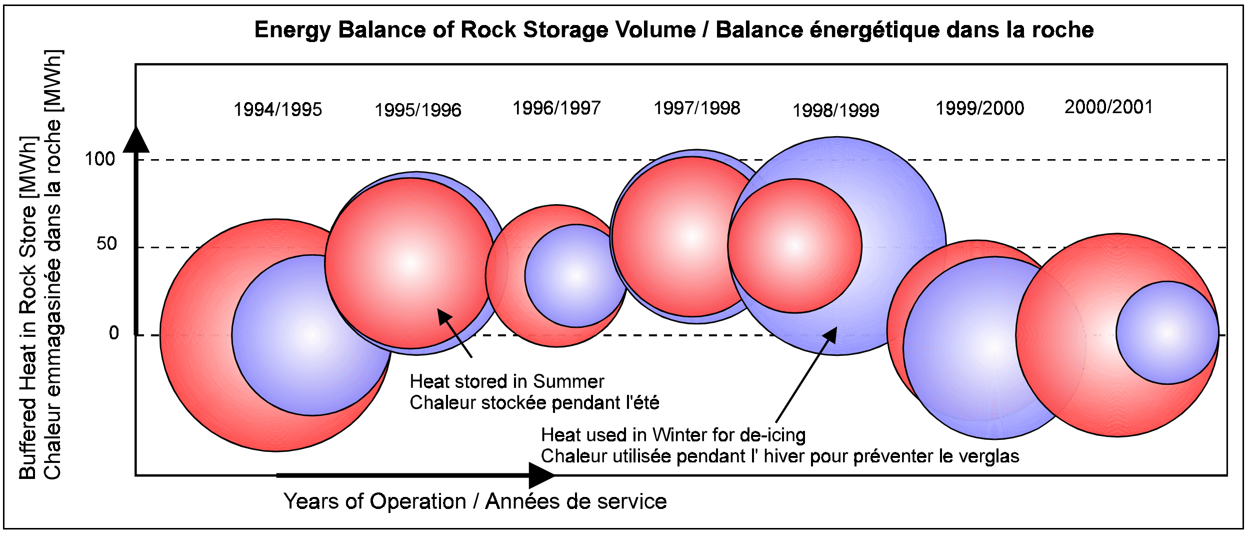

Figure 3 – Energy balance for the seasonal heat store (from SERSO measurements)

This gentle and cautiously forward-looking type of Winter operation avoids the sudden demand for high rates of heat delivery at high temperatures to thaw out sudden ice formations or frozen snow covers. In addition it is possible thus to avoid the need for a heat pump.

It is generally possible in the central European Summer to extract more heat from the roadway than will be needed for maintaining freedom from ice in the following Winter. This energy surplus covers the heat loss from the seasonal storage volume. The exception to the rule was the operational year 1998/1999. A system error remained undetected due to human error during the most intensive Summer months, resulting in reduced energy collection.

3.2 Operating Costs

The operating costs for 2000 were CHF 10'750 (US$ 6'300). The proportion of this for maintenance and personnel was relatively high at CHF 6'500 (US$ 3'800). 40% of the remainder went towards the measurement campaign and heating the control room. The other 60% (25% of the total) was for electrical energy for pump operation (see Fig. 4).

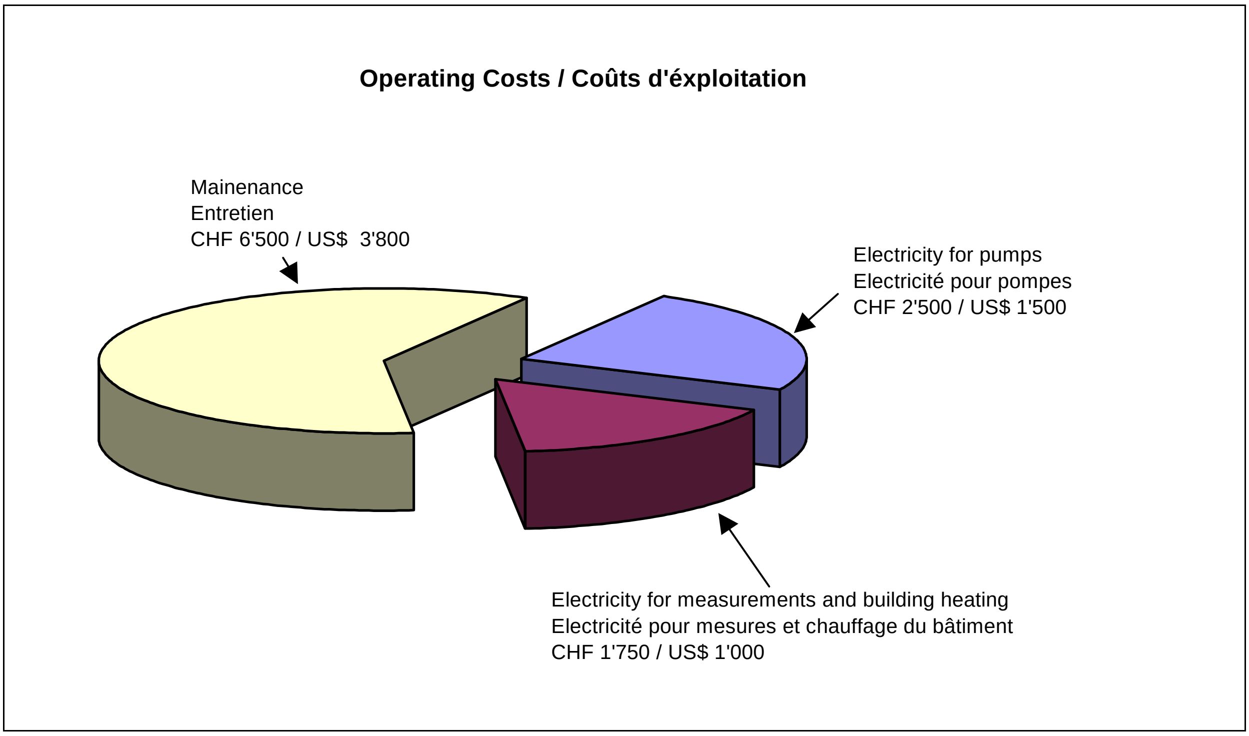

Figure 4 – Operating costs for 2000

3.3 Road Construction And Surface

The stability of the road pavement of the SERSO installation has been remarkable. After more than six years of service, no signs of corrugation reflecting the presence of the underlying heat exchange coils are detectable on the surface. Moreover, despite the sharp curve and the vertical gradient in the road, there has been no rut formation, nor any sign of material breakdown. The stabilizing influence of the heat extraction in Summer, always expected, has been demonstrated. The choice of pavement material always demands that the best compromise be found between resistance to plastic deformation at high temperature and resistance to cracking at low temperature. The heat extraction leads to lower average and peak temperatures both on and in the pavement material and leads to a longer lifetime.

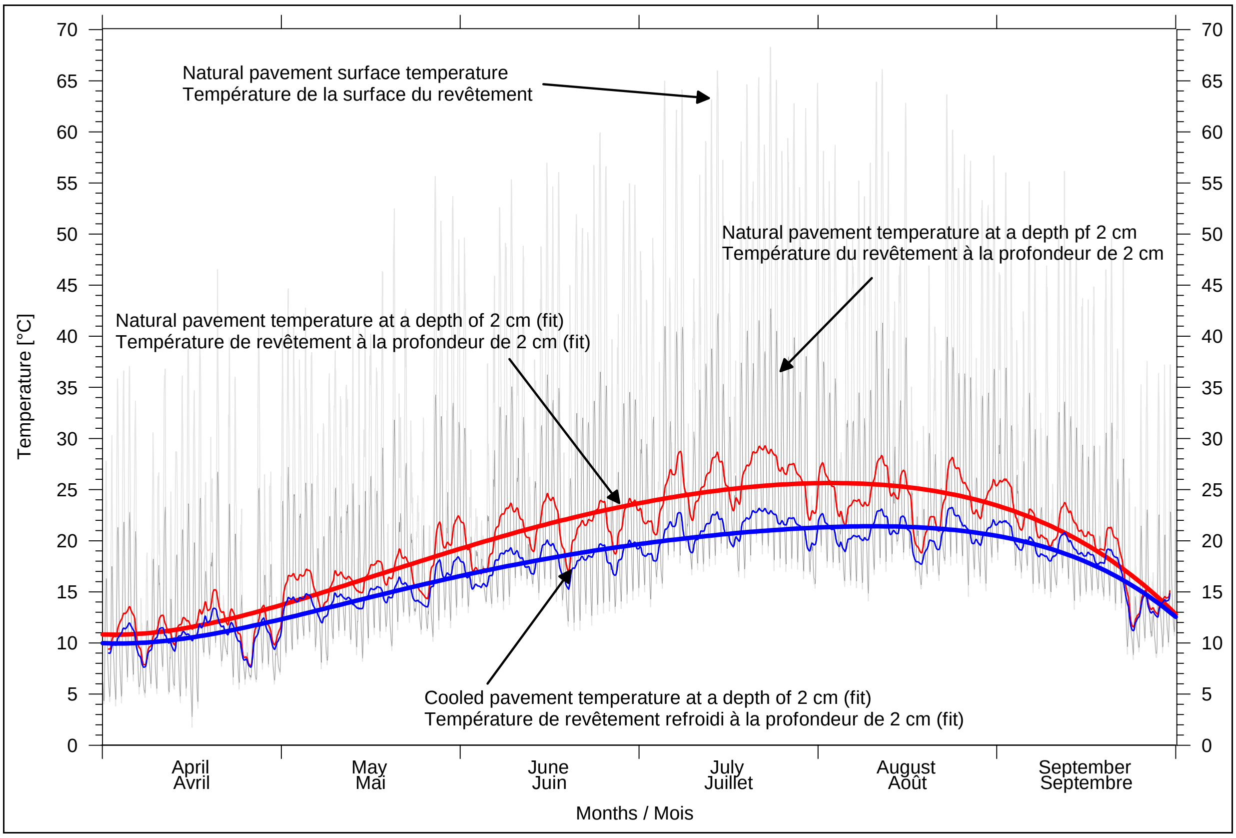

Figure 5 – Computer simulation of the effects of SERSO operation in Summer.

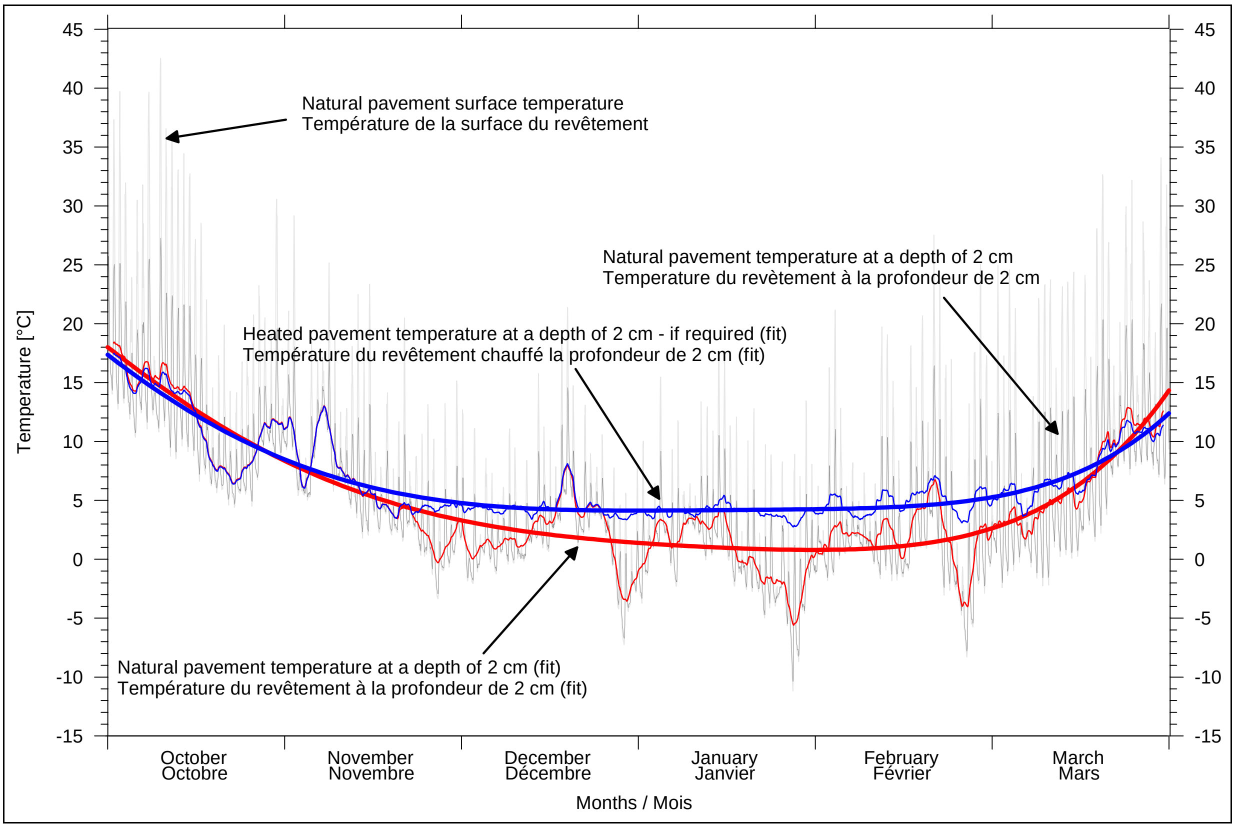

Figure 6 – Computer simulation of the effects of SERSO operation in Winter.

Peak temperatures on the road surface in Summer approach 70°C. Heat diffuses into the roadbed via the pavement's upper wear layer, in the middle of which peaks of 40°C are measured. The cooling effect of the heat extraction reduces average temperatures by around 6K and peak values by as much as 15K. Fig. 5 shows a computed comparison between cooled and natural pavement temperatures.

The attemperation of the pavement in Winter prevents the material temperature from sinking below 0°C. Whereas under natural conditions, temperature in the upper wear layer can sink to –10°C and the surface temperature to well below this level, SERSO operation keeps the minima within the range +2 to +4°C. Fig. 6 shows the results of a computation of Winter operation.

To summarize: the amplitude of temperature variations over a whole year in the road pavement are reduced by seasonal heat extraction and return from over 50K to around 30K. Extreme values to not exceed 30°C, nor sink below 0°C.

4. From SERSO To SERSO-PLUS

Two types of application are foreseen for applying conceptual and design developments to the original SERSO system:

- local application at known accident spots and at heavily used traffic nodes;
- application over a broad area on and around a busy express road.

Sufficient knowledge has been acquired already for handling the first of these applications. However, the areal use of SERSO to guarantee the full availability of entire sections of heavily loaded express roads is a new and considerably more complex task.

Ice and snow control in dense traffic on expressways and motorways is particularly difficult, in effect almost impossible, under rush-hour conditions. In rush-hour peaks the combination of ice or sudden snowfalls with accidents or with the normally expected traffic interruptions and jams can stagnate traffic flow for long periods. Stopped traffic permits the immediate build-up of snow and ice layers, so that hours can pass before the stranded vehicles can be moved. The situation is aggravated by the fact that the service vehicles of the road department (e.g. snowploughs and salt distributors) are also paralysed by the traffic jam. Much time and effort on the part of the service personnel is required, even after relief of the jam. Large quantities of ice removal chemicals are typically necessary to restore the traffic lanes to its normal safe state.

A developed version of SERSO offers a solution to such situations. Its task is to assure that the traffic lane pavements, during the critical times in the Winter, are maintained at a slightly raised temperature to hinder and delay ice or snow build-up on the surface. It will thus be possible to reactivate the traffic flow immediately after clearing jams due to accidents or other causes. In addition to the reduced costs of road service and accident follow-up the costs of financial losses due to the delays is also to be expected.

5. The SERSO-PLUS Installation

A SERSO-PLUS system consists essentially of the under-pavement heat exchangers covering the area of the traffic lanes and a range of various heat sources situated directly in the neighbourhood of the road. It is important that all elements of the system must be so conceived as to allow the integration of their construction or installation into the work flow of a road pavement replacement programme.

The heat exchanger components will be installed mechanically in a special intermediate layer incorporated in the new roadway. The top wear layer forming the running surface may then be renewed as necessary at later times in a conventional manner.

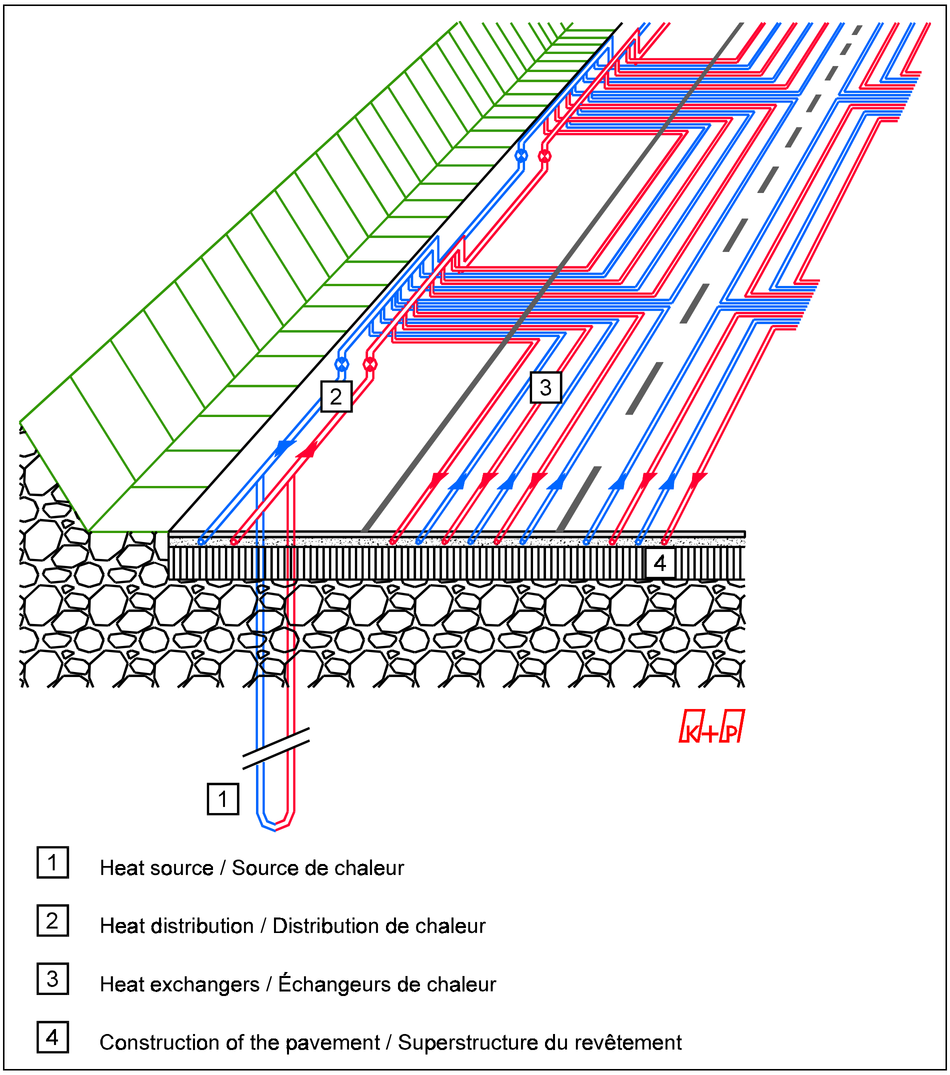

Figure 7 – System diagram of the heat exchange tubing in the pavement

6. Feasibility Of SERSO-PLUS

6.1 Technical Feasibility

The components as used in the SERSO system, and particularly the components in the road itself, cannot simply be built into a SERSO-PLUS system despite having proven themselves satisfactory. Now there is a need for practical solutions with novel materials, modular designs and mechanised fabrication and installation techniques to minimise costs whilst maintaining quality and longevity.

The experiences from SERSO have to be adapted to other types of roads and other road constructions. It will be necessary here to develop new concepts, for instance for laying down the heat exchangers, for the build sequences in road construction or renewal and for road pavement design.

Material choice, fabrication method and installation technique for the heat exchanger must be viewed as integral parts of the concept. There are other tasks too: heat collection and supply must be efficient under all road conditions – in cuttings, on flat ground and on embankments, as well as on bridges, viaducts and ramps. The very basic task of integrating the building of a SERSO system into a road renewal programme without unduly lengthening the timescale has to be undertaken.

6.2 Operation And Energy Fluxes

There are at each site at which a SERSO-PLUS installation is to be built a number of vital parameters, which can only be studied via model simulation. These are used for the sizing and design of the individual components and the determination of the operating strategy. Important is, for instance, the temperature distribution throughout the pavement. The road surface temperature, for instance, varies continuously and at any time is dependent upon air temperature, global radiation intensity, wind strength and direction, precipitation and temperature and flow rate of the heat exchange fluid in the heat exchanger tubes. Using information on the situation and orientation of the road, on the material properties of roadbed and pavement, on possible additional heat sources and sinks and on all details of the heat exchanger geometry, several years of operation and several critical weather scenarios should be modelled.

6.3 Overall System Economics

The final and most important step in establishing the viability of the SERSO-PLUS system is the execution of an economic study. A cost-benefit analysis is underway for which elements of the costs and the benefits have been systematically assembled for a specific application. Intangibles were valuated for expression in monetary terms using existing methods. The economic calculations are to be made available to interested users and investors as a decision aid.

The influences of the SERSO-PLUS construction, and operation installation, in particular in the operational and political economics domains, are calculated in order to arrive at values for the net costs and benefits. A comparison is always made in these domains between the road with and without the SERSO-PLUS system. Data for the analysis is being taken over from the technical feasibility studies for energetic and construction aspects, from literature and records on the political economic consequences of traffic delays and from records of the social costs of road accidents and the external cost effects on the traffic in the agglomeration.

Elements of cost used are:

- the construction costs (two alternative projects at the same site are considered, one for a new road and one for a road renewal);
- operation and maintenance costs of the system;
- maintenance costs of the road pavement;
- management of the system operation and performance;
- effects of the system on functional lifetimes of civil works;
- amortisation costs of all system components;
- risk-based costs arising as a result of system failures and material damages

The benefits considered include reductions of accident costs, of the costs arising from traffic jams, of maintenance work, of the use of material and equipment and finally the reduction of rut formation and wear during the Summer leading to extended lifetime. On the other hand, alternative costs and additional costs to the user are considered.

7. Future Prospects

The growing importance of maintaining full availability of motorways and expressways and need to overcome the difficulties experienced in guaranteeing this service under dense and disturbed traffic conditions in Winter, lead to plans for a developed version of SERSO. The feasibility study for SERSO-PLUS shows its potential effectiveness. The global economics are demonstrated, but the work continues to point out questions still to be answered. It is possible that some practical tests will have to be undertaken prior to the start of routine use of the technology. The installation of a SERSO-PLUS system is planned for a densely loaded section of the Swiss motorway network, due for renewal in the near future.

8. Relevant Literature

There exist a number of unpublished reports on theoretical and experimental studies from the pre-study, design and construction phases of the SERSO project. In addition, six-monthly reports were produced on operational experiences starting from plant commissioning in 1994. These reports were produced under contract to the Office for Roads of the canton of Bern, Department for operation and maintenance (Tiefbauamt des Kantons Bern, Abt. Betrieb und Unterhalt), CH-3011 Bern.

The following publications are available:

SCHLUP, U.; SCHATZMANN, J. (1998): L'énergie solaire pour limiter le verglas - Rapport technique Volume. 2. Xème Congrès International de la Viabilité Hivernale de l'AIPCR, Mars 1998, Lulea, Suède.

HOPKIRK, R.J.; HESS, K.; EUGSTER, W.J.; KNOBEL, P. (1994): SERSO - Pilotprojekt zur Sonnenenergierückgewinnung aus Strassenoberflächen. Editors: Bundesamt für Strassenbau und Tiefbauamt des Kantons Bern. August 1994. For information contact phone: +41-31-633-3582.

EUGSTER, W.J.; HESS, K.; HOPKIRK, R.J. (1996): SERSO - Mit Sommer-Sonne gegen Winter-Glatteis. Proc. 4. Geothermische Fachtagung GtV, September 1996, Konstanz.

RAUBER, M. (1995): Energy from Road Surfaces. CADDET Renewable Energy Newsletter 1/95. January 1995.

For further information the following web sites are recommended:

http://www.polydynamics.ch
http://www.geothermie.de