"Energy from asphalt pavements"

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ABSTRACT
This paper describes Road Energy Systems® (RES) asphalt solar collector a system for extracting energy from asphalt pavements which have been developed and commercialised in The Netherlands by Ooms Avenhorn Holding bv and introduced to the UK through licensee Invisible Heating Systems assisted by Material Edge Ltd, Ooms UK representative.

The heart of the system is an energy recycling network of pipes which is integrated into a variety of asphalt pavements.

The paper describes the history of the systems development and site trials; it discusses laboratory work and finite element analysis necessary to ensure the system would work in practice. Dutch case histories are briefly described and shown.

The paper goes into detail on the successful first UK installation in June 2006 at Ullapool Scotland. The preparation and suitability of surfaces, spraying of bituminous bond coat layers, laying of grid and pipe structure and paving of asphalt layers are described and discussed.

The UK case history describes the generation of all the needs of an office block for hot water, heating and air conditioning together with the additional advantages of de icing in winter and cooling in summer of the car park pavement.

The technical requirements for the individual elements; surfaces, bond coats, grid, pipes and polymer modified asphalt, that make up the system are also described.

Regulatory approvals are discussed and financial benefits versus other systems such as conventional heating and solar panels are shown.

1.1 *History and the Dutch experience.*

In 1997 a consortium consisting of several types of companies (Ooms Avenhorn Holding, WTH vloerverwarming and TipSpit) was founded to develop a system of converting energy absorbed by asphalt from sun and cold conditions to a reusable energy resource.

Road Energy Systems® as it is known works as follows: in summer, cold water is pumped up from a specific underground storage medium (in the Netherlands often an aquifer) and transported through pipes in the upper part of the asphaltic layers of a pavement. Due to the effect of the sun, the water gets warm.

Via a heat exchanger, this heat is transported into another underground reservoir (the so-called hot store) and held at this location until required. In winter, the system operates in the opposite way. The stored previously heated water flows from the hot storage medium to the buildings for heating purposes and once utilised through the asphalt pavement for de-icing purposes.

The asphalt-aquifer system described above, also cools the pavement in summer (thereby reducing rutting) and heats the pavement in winter (thereby eliminating icy driving conditions and asphalt cracking).

It is obvious that the most cost-effective and environmentally friendly way of exploiting the investments required for this system is obtained by utilising the energy gained in buildings via heat pumps. In particular the cooling of buildings in summer provides a highly efficient method compared with the high consumption of electricity fuelling air conditioning units. Figure 1 illustrates the way in which the so-called asphalt collector can be utilized.

Figure 2 Overview of the prototype test site.

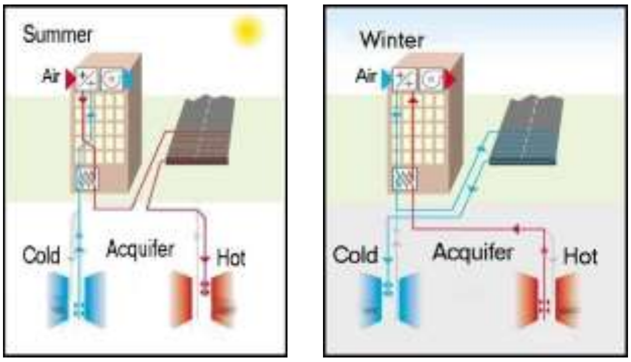

Figure 1: Summer and winter storage and utilisation of hot and cold water.

To enable reliable thermal design of these types of systems, an in-situ testing programme was carried out in Hoorn, the Netherlands between 1998 and 2001 [*deBondt et al 1998-2001]* . It consisted of measuring temperatures and flows at about 150 locations along different constructions of specially prepared (instrumented) pavement sections. Figure 2 gives an overview of the location, Figure 3 shows typical data from these test sections [*Loomans et al 2003].*

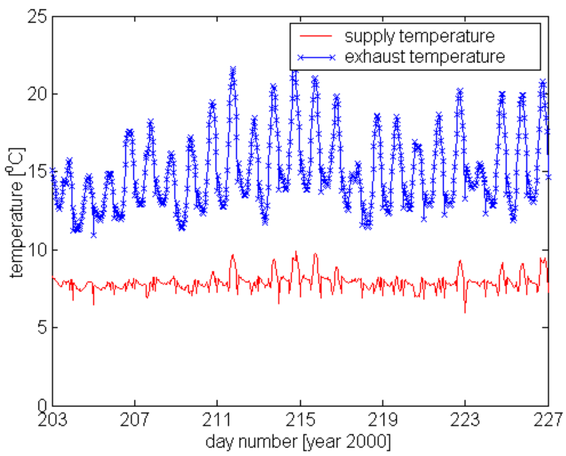

Figure 3 Typical Example of Measurements (Input and Output)

The energy (heat as well as cold) which can be generated by an asphalt collector depends on a large number of parameters, such as the input temperature of the fluid which is used as a transport medium, the flow, the depth of the pipes within the pavement structure, the thermal properties of the materials of the pavement structure, etc. By using the data from the Hoorn test sections, a computational tool has been developed, which is capable of assessing the performance of the asphalt collector for climatic conditions other than the Netherlands.

At the Scharwoude site, an extensive monitoring project continues with the purpose of providing a) long-term experience with respect to control strategies, reliability, etc. and b) data on temperatures, flows and energy requirements on all key elements of the total system (asphalt collector, underground storage reservoir and buildings). The data is utilized to verify a software tool (PIA-RES®), which has been developed for the analysis of the interaction between the asphalt collector, the underground storage system and the energy demand
(heating and cooling) of the buildings.

Figure 4. Overview of Final Asphalt Solar Collector System

1.2 *Road construction aspects*

Since the Hoorn test sections were part of a heavily loaded route for the transport of sand and aggregates, with slowly driving (overloaded) trucks, the situation was ideal to test also to what extent the system could be optimized with respect to the laying process and durability under mechanical loadings. Key factors (targets) in the development phase were that a) the construction of an asphalt collector should be possible in a short period of time, in order to keep the possibility that it could also be applied on existing pavements and b) that one could be sure that the presence of the pipes would have no detrimental effect on the lifetime of the pavement. Via several steps (using several prototypes) the system shown in figure 4 has been found to be the optimum one.

1.3 *Projects in the Netherlands since 1998.*

Ooms Avenhorn Holding has already successfully completed several projects in the Netherlands with Road Energy Systems® , such as:

Several offices in Scharwoude, municipality of Wester-Koggenland (2,250 m²)
Industrial site Westfrisia Oost III in the city of Hoorn (3,350 m²)
Parking lot near an office building in the city of Dordrecht (450 m²)
Viaduct in the city of Rotterdam (10,000 m²) where the principal purpose was for de-icing a large elevated structure into the port.

EMVO platform airport Woensdrecht (7,500 m²)
Industrial site, 't Zand (2,200 m²)
70 care houses in the municipality of Wester-Koggenland (850 m²).
Road adjacent to apartment building in Zoerle-Parwijs, Belgium; 700m²

RES asphalt solar collectors can also be used on airports. Various feasibility studies (airports of Eindhoven and Woensdrecht) are showing that energy from asphalt is a very good option for airports. Ooms Avenhorn Holding has constructed an apron on the airport of Woensdrecht, the Netherlands in which RES asphalt solar collector is combined with a special asphalt wearing course. This asphalt, with Sealoflex® SFB5-JR bitumen, is kerosene-resistant.

The UK's first RES asphalt solar collector project.
In January 2006 Invisible Heating Services were appointed as the licensee for Scotland of the Road Energy Systems®.

Invisible Heating Systems already had an excellent track record of installation of under floor heating systems and heat pumps which were utilising energy from solar panels and geothermal sources so the only differences were in the areas of heat and cold production under asphalt.

Material Edge Ltd the UK representative of Ooms Avenhorn International bv provided support together with Ooms Avenhorn Research and Development in the area of asphalt production and laying requirements. Ennstone Thistle was the company of choice for manufacturing and laying of the asphalt required on the first UK project in Ullapool, Scotland.

The sequence of installation procedures are as follows.

Geotechnical investigation to ensure suitability of groundwater conditions for storage and retrieval of hot and cold water sources.

Prepare site up to road base level to conventional pavement designs appropriate to the traffic requirements.

Ensure a regulated, smooth, closely graded surface free from dirt and completed dry is prepared prior to spraying with hot bitumen.

Spray surface with hot Sealoflex® polymer modified binder from a suitable spray tanker using the spray bar or hand lance. Spray rate dependent on condition of surface, type of pavement and anticipated traffic loads.

Apply RES grid to the area, cutting as required around ironwork and other obstructions.

Apply second application of Sealoflex® bond coat.

Install pipe work into RES grid in accordance with plans produced from RES software CAD drawings. Link to manifold for connection to ground pump.

Any pipe work damaged during installation to be replaced prior to overlay. Cold water is run through the pipe work during laying to reduce the risk of melting of the pipe and to allow capture of the heat of the asphalt which is used to charge the aquifer strata with hot water from day 1 of the installation.

Pave at about half normal speed ensuring all vehicle tyres are thoroughly wetted to avoid sticking with bond coat and potential for pulling out of pipes. Tracked pavers are preferable to wheeled pavers but not essential.

Utilise suitable deadweight rollers without vibration dependant on binder course being used.

It was found possible to follow the above procedures without variation. Wet weather caused some delays in the speed of progress of the project and rain had to be vacuumed out of the grid structure prior to spraying the second application of Sealoflex® bond coat. However a conventional road sweeper provided this function adequately.
No pipe breaks were experienced during installation of the pipe work or subsequent overlay and no pipes were picked up by wheels of delivery or paving machines. The installation was all in all event free baring the weather considerations.

Thermal imaging cameras are now available at reasonable cost and through their use it is possible to see the heat distribution throughout the pipe work and asphalt during installation and paving. Once paving had commenced the pipe loops which were running cold water through the paved area lit up in red to reveal the capture of hot water. This was pumped to the aquifer for later use. The cooling asphalt can be seen moving from green to blue colour in the background.

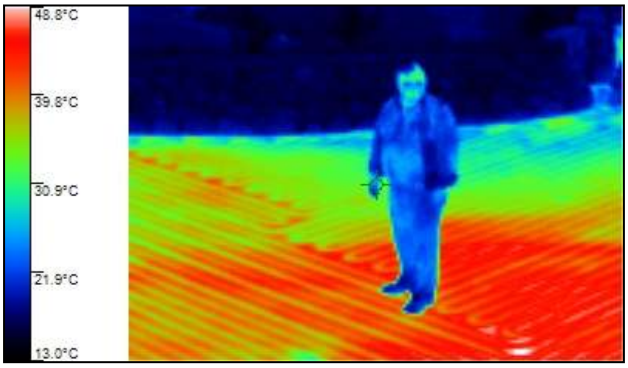

Figure 5 Thermal image of hot water resulting from paving operation.

On the following day the 30mm surface course was laid. This was a proprietary mix from Ennstone Thistle recommended for use in car parks to reduce scuffing from power assisted steering.

1.4 *Critical Aspects of the RES asphalt solar collector.*

1.4.1 *Physical properties of materials*

In order to make it possible for the system to become commercially acceptable, since 1998 several (innovative) actions have been carried out by Ooms Avenhorn Holding to prove the system. These include:

a new laboratory test set-up was created to simulate the effect of the asphalt compaction process on the (plastic) pipe, needed for the pipe selection process.

a three-dimensional grid was developed to fix and protect the pipe during the laying and compaction of the asphalt mixture.

special grips were made to enable grid testing in the laboratory.

optimization of laying techniques and procedures for the pipe as well as the grid (also near pavement edges, around corners, in curves, etc.)

development of a tool for the estimation of the required cooling equipment for the system during the laying of the (hot) asphalt mixture

adaptation of routine road construction quality control procedures

finite element computations on pavement engineering aspects, see Figure 6 [*van Bijsterveld & de Bondt, 2002.]*

establishing a pavement design approach for asphalt collector systems

development of a special Sealoflex® polymer modified bitumen which provides a high quality asphalt mixture in between the pipes and the grid. Criteria for the bitumen development were: a reduced viscosity (also to fill the 'gaps'), a good low temperature performance (cracking resistance) and a good high temperature performance (rutting resistance). The latter was achieved using the zero shear viscosity as a parameter. Fuel resistant binders (in both the asphalt and the bond coat) can also be used if required at airports for instance.

tests on system extension and repair (the latter for instance in case of traffic accidents)

working on a recycling procedure to ensure that this is possible in future

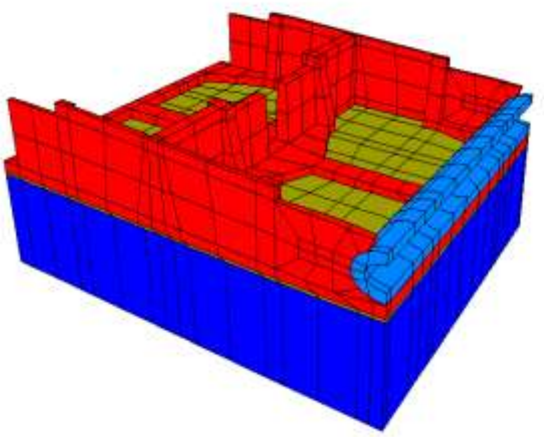

Figure 6 Finite element simulation of asphalt collector system

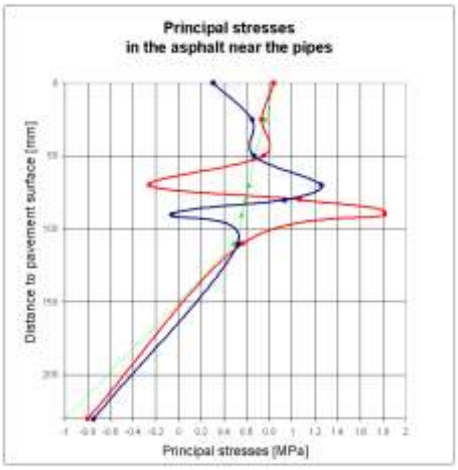

Figure 7 Stress concentration in the asphalt without special measures

The presence of the collector system in the pavement is an interesting pavement engineering challenge, because the consequences of the introduction of a pipe close to the surface of a "standard" pavement structure is that around the pipe high stresses are developed during the passage of a wheel load. See Figure 9. [van Bijsterveld, 2000, van Bijsterveld & de Bondt 2003].

The way in which this problem has been tackled is that a relatively soft asphaltic mixture is used, which has a high resistance to cracking due to stress concentrations. Furthermore, the presence of the three-dimensional interlocking grid reduces crack growth. The expected risk for permanent deformation, when using a softer asphaltic mixture, is taken into account by the presence of the grid, the cooling generated by the system itself and modification of the bitumen by means of polymers. With the latter option, the mixture design can be adapted to the traffic loadings which can be expected (regular trucks, or e.g. aircraft on platforms).

1.4.2 *Practical installation requirements*

These are covered in UK's first Road Energy Systems® project above.

Regulatory authority approvals

Due to the highly novel nature of the system it took some time to establish which authorities must be notified and from which approvals were required. The following is a list of those that must be contacted and some of the experiences.

Investigations into legal aspects (ownership, responsibility, maintenance, etc.) with respect to placing a collector system in a pavement

inventory of organizational procedures for the exploitation of the energy

Approvals by local planning departments and highways authorities

Approvals by water companies to allow the use of aquifers to store hot and cold water

1.4.3 *Dutch experience on groundwater approvals.*

In general in the Netherlands there are three layers of sand separated by layers of clay that can be used to store energy. According to the directive 2000/60/EC, establishing a framework for Community action in the field of water policy, some areas are allocated to collect drinking water or are protected as a strategic drinking water reserve. The Netherlands has salt and sweet water areas and it is not permitted to mix those two types of water.

When using an aquifer to store energy you have to comply with the Dutch groundwater law "Grondwaterwet". It generally says that you have to get a permit from the provincial authority. Every provincial authority has its own interpretation which results in different rules for different locations. In general the daily average water temperature in the underground storage has to stay between 5 and 30 degrees Celsius (of course with some exceptions).

It takes a few months to get a permit to place energy storage into an aquifer. After some investigation we found out that the maximum temperature allowed in the aquifer is derived from the maximum temperature allowed for water for human consumption of 25° C as written down in the directive 1980/778/EC, relating to the quality of water intended for human consumption.

In Scharwoude (where Ooms' head office is located) we are using open "duo" wells in the second sand layer between 50 and 70 m which means that for a half year you take out ground water from one well and put it in the second well. The following half year you take ground water from the last well and put it back in the first well. The energy is transferred from and to the aquifer system through a heat exchanger. Using a heat exchanger also ensures that the groundwater is not in contact with any other medium or human being.

The warm or cold groundwater replaces the water in the sand layer and slowly releases its energy to the groundmass and loses its energy as it moves further away from the core of the well. Getting the energy back from the aquifer, groundwater is pumped up from the well. The groundwater is moving through the warm or cold ground mass and takes up the energy until it arrives at the core of the well. When there is none or only minor groundwater movement the energy stored will stay in its place and therefore not affect the surrounding area. Before you introduce energy storage into an aquifer you do have to investigate the location by studying information of earlier placed wells in the near area or by a test drill so you can measure the groundwater movement.

The possible problem of the growth of bacteria by higher aquifer temperatures has not been shown in projects in the Netherlands. Increasing the temperature alone will not automatically result in bacterial growth. Therefore other conditions must also be right. For example the amount of nutrients and the oxygen level have to be high enough to support the growth of bacteria. In nutrient and oxygen poor groundwater the possibility of bacterial growth is therefore negligibly small but not 100% excludable. Above 70° - 80° C bacteria will be killed. When you increase the average aquifer temperature, above 40° - 50° C then it is possible that the increased temperature affects the equilibrium of the solubility of salt-ions in groundwater. Instead of the bacteria, ions will probably not stay at the aquifer location. There are aquifers in the Netherlands where it is permitted to store water of 40 degrees Celsius.

When the energy storage is operated as we do in the Road Energy Systems® in the Netherlands, we control the inlet temperature of the well by adjusting the water flow through the asphalt solar-collector. and the energy balance over a couple of years is zero. In these circumstances there are no reported problems.

1.4.4 *Financial returns on investment.*

Costs and comparisons with other systems.
RES and asphalt combined cost
£90-£100/sq.m.
Extra over to surfacing alone costs
£30-40/sq.m.
Conventional solar panels cost about £400/sq.m.but are twice as efficient.
Therefore Capital cost of RES=1/5th conventional Solar panels
Running costs 1/5th equivalent Gas heating only system.
Geo / drilling costs are site dependent.
Cooling ability effectively doubles energy savings achievable.
System generates heat or cold 100% of the time not just during daylight.
Possible Capital allowance of up to 30% means RES system could costs £10/sq.m. or less.
Grant assistance available from most Councils.
Return on capital investment within 8 years.
RES generates 250kW/sq.m. per year.
Reduce temperature needs to 14C for warehousing reduces asphalt area to 25% of building meterage.
Zero visual or noise environmental impact as system is hidden once installed.
No de icing salts or chemicals required on roads, airfields and elevated structures otherwise subject to corrosion.
Reduced accidents due to “always on” de icing.
Improved road life due to cooling of asphalt in summer and warming in winter.
Non fossil fuel air conditioning in floors and ceilings of buildings.

1.4.5 *Reduction in CO2 emissions*

The following table shows actual comparative results from the office site at Scharwoude. The main conclusions are:
Reduction in CO_2 out put in summer versus air conditioning 87%
Reduction in CO_2 output in winter versus gas heating 25%
Average CO_2 reduction at Scharwoude site 45%.

Table 1 Comparison of Road Energy Systems® and conventional energy used at Scharwoude office site.

Comparative energy demands of conventional and Road Energy Systems

		Road Energy	Reference system Gas heater and aircon unit
Summerseason			
Cold demand summer 2004	MWh_{th}	115	115
Electricity needed	MWh_{el}	4,8	38,3
Cooling performance		24	3
CO_2 emissions	x 1000 kg	2,5	19,8
Reduction CO_2 on cooling		87,4%	
Winterseason			
Heat demand winter 2004/2005	MWh_{th}	185,7	185,7
Electricity needed heatpumps and aquifer pumps	MWh_{el}	61,4	0
Gas needed for heating	m³	0	23759
Efficiency for heating with system Ooms		3	-
Efficiency for conventional heating		0,8	0,8
CO_2 emissions	x 1000 kg	31,8	42,4
Reduction CO_2 on heating		25%	
Whole year			
Delivered cold and heat		300,7	300,7
Electricity needed	MWh_{el}	66,2	38,3
Gas needed	m³	0	23759
CO_2 emissions	x 1000 kg	34,3	62,2
Reduction CO_2 emission with energy system Ooms		45%	

Table 2. Cost comparison for gas heating, solar heating of hot water and Road Energy Systems.

Capital and running cost comparisons	Conventional (gas heating only)	Road Energy Systems ® (heating and cooling) [250kW/sq.m./yr]	Solar panels (heating only) [500kW/sq.m./yr]
Initial costs	£60/sq.m.	£90/sq.m.	£400/sq.m.
Running costs	3p/kW.	0.6p/kW.	0.6p/kW.
Total life cycle costs per year (20 year life, 1000sq.m)	£10,500	£6,000	£11,500

1.5 *Conclusions*

The Road Energy Systems® Asphalt Solar Collector developed in the Netherlands have been proven as a commercially viable energy efficient replacement for hot water, heating and cooling generation with the additional advantages of de icing and cooling of pavements.

Based on experience of Netherlands projects and ground conditions it can be stated that a modern office building with a floor space of 10,000m²

Needs an asphalt solar collector of roughly 400m²

Requires a pumping capacity of roughly 110m³/h for the hot well and cold well water flows.

Needs an installed total heat pump capacity of roughly 340KW

Produces 55% less CO2 than a conventional gas heating and air conditioned office building.

Uses 55% less fossil fuels for heating and cooling.

The system now in its 8th year in the Netherlands has been successfully installed in the UK and much interest in the system has been generated. Enquires being actively followed up or quoted for include:

Homeless sheltered housing project in Leeds
School playgrounds and car parks in Scotland
Major supermarket stores and distribution networks around the UK.
Civil and military airfields
Industrial estates in Ireland

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