EVALUATIONS OF CONCRETE GRID PAVEMENTS IN THE UNITED STATES

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SUMMARY

Although manufactured by many producers of solid concrete block paving in the U.S. and Europe, concrete grid pavements have experienced limited use in the U.S. This has been due to (a) their higher initial cost than conventional asphalt paving, and (b) the lack of research data on grid pavers that demonstrates their benefits arc cocnensurate to their higher costs. This paper describs the kinds of concrete grid pavements manufactured in the U.S. It also reviews recent research there on concrete grid pavements that has been aimed at demonstrating their benefits. The discussion outlines studies undertaken by the author in 1981 that evaluate and compare the ability of grid pavers and asphalt surfaces to (a) reduce stormwater runoff, (b) attenuate pollutants in runoff, (c) decrease ground level temperatures, and to (d) reduce maintenance and energy costs. These studies were conducted at a demonstration parking lot in Dayton, Ohio as a part of a comprehensive, ongoing research by the City of Dayton in applying natural processes to mitigate the environmental impacts of cities.

1. INTRODUCTION

Recent years have witnessed new technologies that incorporate natural processes in solving urban environmental problems. Technologies that use nature's processes are particularly valuable in our era of scarce energy resources, inflation, and limited public dollars. Concrete grid pavements (see figure 1) are an alternative paving technology that combines the environmental benefits of grass with a perforated concrete surface on a sand and gravel base to ameliorate the environmental impacts generated by conventional impervious asphalt or monolithic concrete paving surfaces. The impacts of these conventional paving surfaces are well known—increased stormwater runoff, water pollution, air pollution, and increased ground level temperatures. This paper presents an overview of concrete grid pavements in the U.S. and how their environmental benefits are being quantified and evaluated so that they can be used more effectively in the urban milieu.

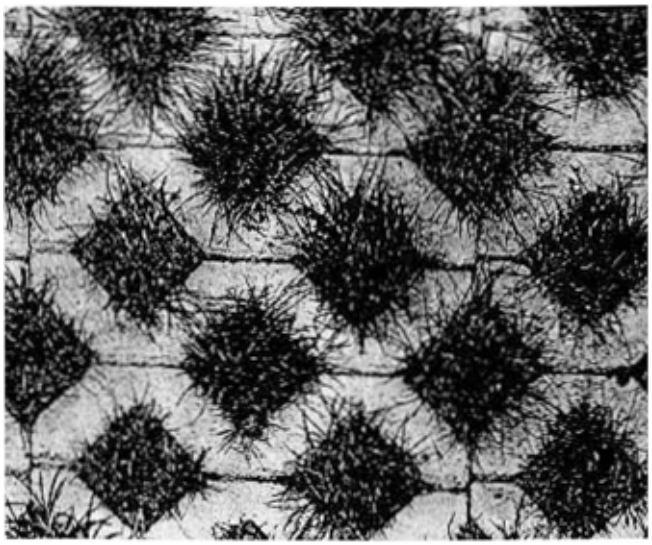

Figure 1: Grass and concrete grids.

2. CONCRETE GRID PAVEMENTS IN THE U.S.

While no precise industry statistics are available, the production of grid pavements in the U.S. ranges between five and twenty-five percent of the total solid block pavement produced each year. Conrete grid pavements marketed in the U.S. fall into three categories: Lattice pavers, castellated pavers, and a poured-on-site type. Lattice pavers have a flat grid-like surface. Castellated pavers are disguished by an uneven surface configuration.

Lattice type products include Turfstone (also Turflock or Turfblock), Grasstone, Unigreen, and Ambigrid brand names. Unigreen is also manufactured with the name Parkpaver and they are Interlocking pavers, as is Ambigrid. Monoslab (sometimes referred to as Grass Paver) and Checkerblock are examples of castellated blocks. Grasscrete is a poured-on-site pavement where thin plastic molds are assembled on-site and laced with reinforcing steel. Concrete is poured into the plastic forms to create a monolithic, flat surface. The plastic in the voids is cut or burned out, then filled with topsoil and grass seed. Figure 2 illustrates the paver types and Table 1 lists their characteristics.

3. RESEARCH AND EVALUATION OF GRID PAVEMENTS

Concrete grid pavements have seen frequent use in Europe to stabilize screambanks and control runoff from paving surfaces, however, their use as a paving surface in the U.S. has been limited. This is due to their two to three times higher initial cost than conventional pavements. Their limited use is also due to the lack of research data on their ability to abate stormwater runoff and water pollution. Such data might Justify their use even as a more costly pavement. Research in the U.S. on grid pavements was a reaction to the Increasing incidents of localized flooding and runoff pollution problems across the U.S. These problems emerged from construction of impervious streets, parking lots, and roads in residential and commercial developments that generate excess volumes of stormwater runoff. Not only is excess runoff

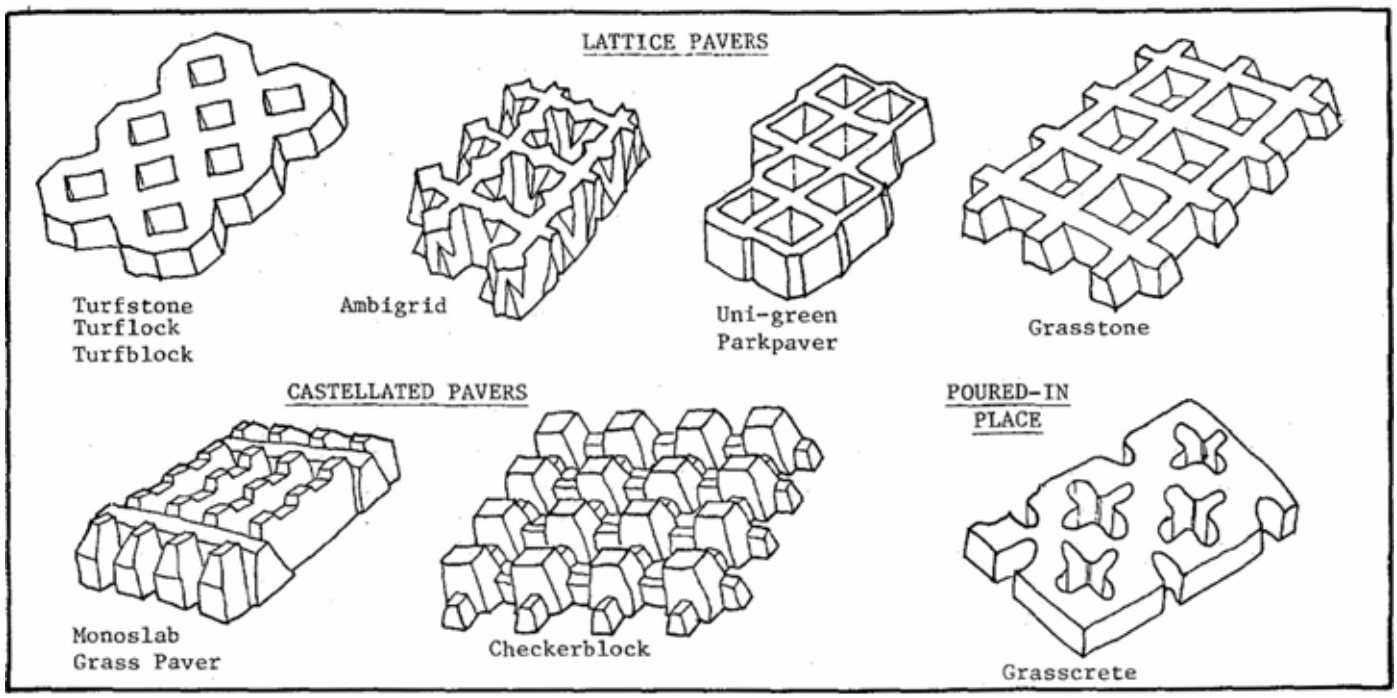

Figure 2: Grid pavement types manufactured in the U.S.

Table 1: Characteristics of concrete grid pavements

Pavement	Length cm	Width cm	Thickness cm	Mass kg	Compressive Strength kg/cm²
Turfstone	60	40	8	27	457
Grasstone	58	44	9	27	527
Unigreen	56	28	11	20	527
Ambigrid	45	29	12.7	25	281
Grass Paver	60	40	11	37	281
Checker Block	61	61	9.5	38	352
Grasscrete	Varies	Varies	10 or 15	Varies	281

generated from these areas, but pollutants washed from them also degrade the water quality of lakes and rivers. In some areas of the U.S., stormwater runoff pollution is a severe threat to municipal water supplies.

The case of flooding and pollution problems arises from short-sighted methods for disposing of runoff. In the past, the prevailing method has been to move it off the site as quickly as possible into storm drains, sewers, and streams. Extensive streambank erosion and pro perty damage from localized flooding has resulted from this method of managing runoff. In response, many municipalities have passed ordinances aimed at reducing excess amounts of stormwater and runoff pollution generated by development. Municipalities have taken this approach when they can no longer afford to increase the size of their storm sewers or when their water supply is becoming polluted.

Engineers, architects, landscape architects, and land developers in response have developed alternative, more nature-like approaches to managing stormwater. For parking lots, approaches include detaining water in remote downslope areas and installing pavement surfaces such as concrete grids that allow for infiltration. Although many municipal ordinances now demand that stormwater be controlled from parking lots, very little data existed specifically on concrete grid pavements that could be used in de signing nature-like drainage systems for them. To generate this data, Day and the author (1) (2) devised laboratory experiments to test observe the runoff characteristics of grid pave ments. An indoor testing- Installation of pave ment that approximated field conditions was used in these experiments. The advantage of using a large indoor facility was that certain environmental conditions could be controlled and

monitored, i.e. the sub-base soil type and the rainfall incensicy (with a rain simulator), as well as easier data collection.

Research by Day (1) in 1980 at Virginia Tech involved testing five concrete pavements in order to determine their runoff coefficients. The runoff coefficient of a pavement equals the volume of runoff divided by the total volume of rainfall. The coefficient is a dimensionless measure from zero to one of the imperviousness of a surface, with one meaning a completely impervious surface. Day's research provided a range of coefficients that can be applied in formulas for designing drainage systems for concrete grid pavements. Day also found that the percent of open area at the bottom of each paver does not play a critical role in the attenuation of runoff. Rather, the surface configuration and slope of the paver influences runoff rates. The castellated pavers reduced more runoff than the lattice type pavements. Day also demonstrated that conductivity of water through the soil beneath the paver-sand-gravel assembly is a major determinant of the runoff coefficient of a paver.

Later research by the author, Day, and Bowers (2) for the State of Virginia used the similar indoor equipment as Day (1) in 1980. This equipment is shown in Figure 3. Three paver types (Turfstone, Monoslab, Grasscrete), top-soil, grass, 5 cm of sand, 15 cm of gravel, and 30 cm of compacted clay soil were placed in three 1.0 in wide by 1.8 m long wooden boxes. A rain simulator produced rainfall that was mixed with measured quantities of typical pollutants found in runoff. Water samples were taken from the surface. Samples were also taken from beneath the pavers in the gravel base, in the clay soil base, and through drains at the bottom of the installation. Ten short duration and/or low intensity rainfall events produced little or no runoff from the concrete grid pavements. A solid concrete slab was also tested as a control. The concrete slab, as expected, had an average runoff coefficient of 0.78. The results of this study showed high rates of removal of pollutants in ten rain events after they filtered through the paver-topsoil-sand-gravel-soil complex. The results demonstrated the ability of concrete grid pavements to allow for the absorbtion of pollutants in runoff, as well as reduce runoff under moderate rain storms.

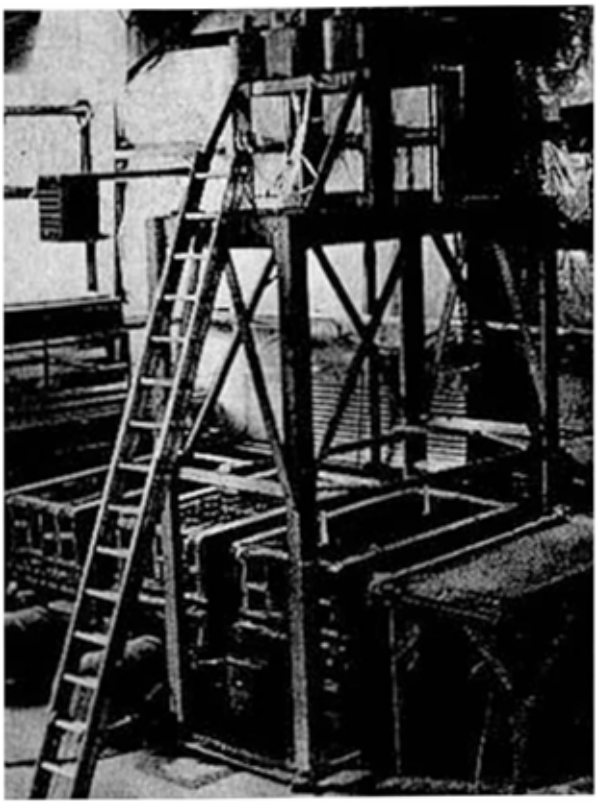

Figure 3: Apparatus used by Day and the author to conduct indoor runoff tests on grid pavements.

4. ON-SITE EVALUATIONS

Three on-site evaluations around the U.S. have focused on studying the drainage benefits of grid pavements. First, an in-situ investigation by Myers and Henkel in Rockville, Maryland (3) using a pumper type fire truck as the source of stormwater runoff showed runoff reductions of fifty to sixty-percent with Monoslab as compared to conventional asphalt paving. Second, recent work in Austin, Texas by Goforth, Diniz and Rauhut (4) for the U.S. Environmental Protection Agency also used an artificial source of stormwater runoff via portable sprinklers. This research compared the stormwater runoff quantities and pollutants from two conventional asphalt lots, a concrete parking lot, a porous asphalt one. and a lot constructed with Turfstone.

The results of this research showed that Turfstone produced the lowest average coefficient of runoff, 0.18 to 0.36, as compared to the other parking lot surfaces. The Turfstone lot also generated lower amounts of water pollution than the other lots. The study further presents two methods for designing grid pavement lots for controlling drainage. The first method is a computer program that enables the user to find the optimum construction of the soil-gravel-sand-paver complex, given a constraint on the runoff discharge rate from the lot. The model can be used under any user-defined rainfall event. The second method uses a simpler approach to parking lot design by following a 8tep-by-gtep procedure to compute discharge with a small calculator.

The third comprehensive on-site study of grid pavement occurred in Dayton, Ohio by the author. Since 1976, the City of Dayton has been exploring innovative strategies to improving air quality, water pollution and urban temperatures through modification of the city’s built and natural environment. Interest in this approach began when a former city manager visited municipal officials around Europe to exchange ideas and perspectives on urban problems. While in Stuttgart, Federal Republic of Germany, he discovered a more comprehensive approach toward solving environmental problems. Urban climatologists incorporated the processes of vegetation in attenuating the urban heat island (the phenomenon of warmer city temperatures than those of

the surrounding countryside) and in inproving air quality.

Impressed by the success of Stuttgart's application of climatological principles to the urban heat island, the City of Dayton took steps to institute a similar program called the Dayton Climate Project. Through the Dayton Climate Project, the city has become an urban laboratory for research into the relationships among urban climatology, urban forestry, air and water pollution abatement, and urban economics. Research contributors to the Project include local citizens, universities, regional planning agencies, and various federal agencies including the U.S. Forest Service and the U.S. Department of the Interior.

One such technology used throughout Stuttgart to mitigate heat was concrete grid pavements. Because the pavement contains grass, the surface reduces the absorption of solar radiation and the storage of excess heat normally associated with asphalt or solid concrete parking lots. Evaporation of moisture from the grass utilized considerable heat energy, reducing the quantity of heat in the near-ground atmosphere. The favorable experiences with concrete grid pavements in Stuttgart and in other places in the U.S. convinced the city management to construct a lot in Dayton. Figure 4 illustrates the 2790 m^2 lot after construction. Since the lot was the first concrete grid type to be built in Dayton, the City, through a grant by the U.S. Department of the Interior, conducted a comprehensive evaluation of the parking lot. The evaluation included the parking lot's thermal and drainage performance, maintenance, life-cycle and energy costs. These evaluations are summarized below.

4.1 Thermal Performance

A comparison study was made between the thermal performance of the concrete grid parking lot and a nearby asphalt parking lot of similar size and solar exposure. Measurements were taken for ten consecutive days with an infrared field thermometer and a sling psychrometer. Wind speed, wind direction, and humidity were also recorded. Readings on both parking lots were taken six times daily at three hour intervals from 0730 to 2200. The readings on each lot were taken within 30 minutes of each other.

Table 2 shows a sample of the radiometric and dry bulb temperatures in sun-exposed areas of each lot. The data displayed on this table represent situations where the meterological conditions were similar for several hours prior to the readings. They also represent situations in which air temperature differences between the two lots were at their greatest. Air temperature differences under comparable conditions were recorded on other days, but they were not as great as the ones listed here. There were also some measurements when no air temperature differences were recorded. Such measurements fell on cool, cloudy days. When analyzing the 466 measurements, radiometric temperatures and dry bulb temperatures were strongly related to each other, where the coefficient of correlation = 0.77. Although the increases in radiometric and dry bulb temperatures were not always exactly proportional, the strong coefficient of correlation showed the relationship to be consistent.

4.2 Drainage performance

The Dayton lot was designed as a catchment contained by curbs which drained into one storm sewer inlet located at one corner. A concrete basin beneath the inlet had a 38 cm diameter concrete pipe outlet. This presented an ideal location for monitoring runoff flow. This pipe was fitted with a 38 cm diameter rectangular v-notch weir. A probe was mounted flush



Figure 4: The grid lot in Dayton a few months after completion.

Table 2: Thermal comparisons of grid and asphalt parking lots

Date and Hour of Day	Grid Lot Radiometric °C	Asphalt Lot Radiometric °C	Grid Lot Dry Bulb °C	Asphalt Lot Dry Bulb °C	Weather Conditions and Comments
July 23 1415	39	42	25	27	Cloudy but very bright. Asphalt reading 30 minutes later.
July 24 1034	37	40	25	27	Bright sunlight. Asphalt reading 30 minutes later.
July 24 1351	47	54	27	30	Bright, hazy sunlight. Asphalt reading 30 minutes later.
July 24 1648	39	46	29	30	Bright, hazy sunlight. Asphalt reading 30 minutes later.
July 25 1048	38	43	27	28	Bright, hazy sunlight. Asphalt reading 30 minutes later.
July 25 1645	34	41	29	31	Overcast but bright. Asphalt reading 30 minutes later.
July 26 1046	34	40	27	29	Overcast but bright. Asphalt reading 30 minutes later.
July 28 1338	31	34	26	27	Overcast but bright. Asphalt reading 30 minutes later.
July 29 1703	32	36	23	24	Alternating sunlight and cloud cover. Asphalt reading 30 minutes earlier.
July 30 1405	44	48	25	27	Bright sunlight. Asphalt reading 30 minutes ealier.
July 30 1702	39	44	26	27	Bright sunlight. Asphalt reading 30 minutes earlier.

against the concrete sewer pipe so it would not interfere with flow measurements. A battery powered flow meter, programmed to measure flow rates from the weir, was placed in the catch basin before each rainstorm. The meter was attached to the probe, calibrated, and left in the catch basin to measure flow from the storm. Precipitation was measured with a recording rain gauge. Rainfall measurements were taken froth a building approximately 800 feet from the lot. The gauge was equipped with an eight day clock, and charts that were changed weekly.

Table 3 displays the results of monitoring 11 storm events from July 1 to September 3, 1981. These events were compared to computer simulations of runoff from an asphalt lot of comparable area. Table 4 also shows this data. Each column in Table 4 (noted by a number) is explained below.

1. Date of storm: for reference.

2. Cm of rainfall: measured by the rain gauge. All storms had a greater than 50% chance of returning in a year, i.e., they were smaller than 2-year storms when compared to U.S. Weather Bureau (1955) rainfall records for Dayton.

3. Volume of Rainfall on Lot in m^3: Equals the cm of measured rainfall x area of the lot x a conversion factor.

4. Volume of Runoff in m^ on the Lot. Taken from measurements from the flow meter.

5. Coefficient of Runoff on the Lot: Equals volume of runoff ÷ the volume of rainfall.

6. Coefficient of Runoff used in the computer runoff simulations of the asphalt lot of the same slope and area equals 1.00.

7. Peak Flow of Runoff in liters per second of the grid lot as measured by the flow meter.

8. Peak Flow of Runoff in liters per second simulated by a computer model of the lot as an asphalt surface under the storm events measured by the rain gauge. The model analyzed each storm with the entire lot as asphalt, but with no islands to inhibit the runoff from reaching the storm sewer inlet in the corner of the lot.

The coefficient of runoff and peak flows measured on the grid lot are substantially less than those simulated for an asphalt lot. The only exception is the last storm event where

Table 3: Stormwater runoff comparisons of a grid and an asphalt lot

Date (1)	Inches of Rainfall cm (2)	Volume of Rainfall m3 (3)	Volume of Runoff m3 (4)	Coefficient of Runoff Grid Lot (5)	Coefficient of Runoff Asphalt Lot (6) -	Peak Flow Grid Lot Ips (7)	Peak Flow Asphalt Lot Ips (8)
July 1	4.06	111.13	10.78	0.10	1.00	9.2	60.8
July 13	3.30	92.04	18.34	0.20	1.00	21.8	223.6
July 21	0.41	11.42	0	0	1.00	0	3.1
July 27	0.81	22.73	0.69	0.03	1.00	0.1	7.5
July 28	0.13	3.77	0	0	1.00	0	3.8
Aug. 3	0.10	2.97	0	0	1.00	0	1.5
Aug. 5	1.70	47.70	5.84	0.13	1.00	2.8	19.5
Aug. 7	0.41	11.42	0.76	0.08	1.00	1.1	14.1
Sept. 1	1.93	53.09	13.50	0.25	1.00	12.7	21.5
Sept. 2	0.69	19.11	0	0	1.00	0	28.9
Sept. 3	1.68	46.72	16.31	0.35	1.00	20.9	24.4

the peak flow is near that of the simulated asphalt lot. Wet soil conditions generated by prior two days of rain probably contributed to the higher peak flow. The grid lot is following the typical pattern of grass surfaces where more runoff is generated under wet antecedent soil moisture conditions. The coefficients of runoff derived from the grid lot are similar to those for grassed surfaces, 0.05 to .035 depending on slope and soil type. The coefficients are also very similar to those reported by Day (**1**) and Goforth et al, (4) who tested for off coefficient of Turfstone.

4.3_ Maintenance

Wear and maintenance were documented on the Dayton lot between the months of January and September, 1981 through a visual survey. The survey recorded the condition of the grass and the pavers. The results of that survey showed that the grass growing in the pavers was cut every two weeks, but only in remote areas that did not experience some withering if cars were not moved daily so that sunlight could reach the grass. Some pavers came loose due to settling and were re-installed with a tighter fit. Snow was removed without difficulty by plows with rubber edges so the pavers would not be damaged.

4.4_ Energy use and life cycle costs

Energy use was estimated for the grid lot in Dayton and it was compared to a conventional asphalt parking lot of similar size. Although exact energy use comparisons were difficult to make, the grid lot appears to hold the advantage of lower manufacturing, construction, maintenance, and recycling energy use when compared to an asphalt lot. Both cement and asphalt manufacture are energy intensive proces ses. Cement manufacture, however, uses more domestic' energy sources such as coal which contributes to greater national independence from imported energy. Grid pavement manufacture requires very little energy when compared to the heating and drying processes required for producing asphalt concrete. In their construction, grid pavement lots use lower amounts of petrol eum energy and are labor-intensive projects, whereas asphalt lots require petroleum-consuming machines for construction. Both asphalt and concrete grid surfaces can be recycled, but the asphalt and aggregate must be removed and processed into a new asphalt batch. Concrete grids, however, can be recycled by merely placing them in a new location. Any broken non-reusable grid pavers can be crushed and batched with new concrete grids. These energy differ ences should be major considerations in the selection of paving materials, especially as world oil supplies diminish and U.S. aggregate supplies tighten in the next decade.

In evaluating the life cycle costs of the Day ton lot, its installation, maintenance and recycling costs were estimated and compared to asphalt parking lots over a twenty year life. Installation cost comparisons showed that as phalt lots are less expensive to install than the grid lot. Since no long term maintenance records have been kept on comparable grid and asphalt lots in the U.S., reasonable assump tions were made regarding their care over twenty years. Depending on the degree of use, asphalt lots require sealing, resurfacing and restriping over their life. Grid lots require none of these. Instead, mowing, with occasional fertilizing and watering is what most grid lots require. These activities are less expen-

sive than those mentioned for an asphalt surface. Furthermore, the modular nature of grid surfaces allows inexpensive access to under ground utilities. Grid pavement also holds a cost advantage over asphalt pavement in recycling. At the end of the life of a grid lot, a large percentage of pavers can be reused else where. Asphalt, however, must be completely removed before and brought to a batch plant for recycling.

5. CONCLUSIONS

Grid pavement lots appear to have long term benefits that can outweigh their higher initial costs when compared to conventional surfaces. Their benefits emerge from integrating the functions of concrete pavement with the natural processes of grass and soil. This combination can yield lower temperatures, less stormwater runoff and lower maintenance costs. The Dayton lot generated lower air temperatures than those found on an asphalt surface. The lower radiometric temperatures meant that less long wave radiation (7-20 micrometers) was emitted by the grid lot. Less radiated and conducted heat from the grid surface in turn gives greater comfort to pedestrians. Furthermore, expansion of the area of grid lots in concert with other types of greenspace could reduce the air con ditioning requirements for adjacent buildings. The City of Dayton is currently researching the energy cost conserving benefits of greenspace for the entire city through the Dayton Climate Project. Grid lots appear that they can make a contribution with trees, parks, and roof gardens.

The monitoring of stormwater demonstrated the ability of grid surfaces to reduce runoff quantities, which can also reduce the need for large and costly storm sewer pipes. Reduced quantities also means a reduction of the amount of pollutants washed from the lot. Infiltration of runoff allows pollutants in the water to be filtered in the soil. Infiltration also provides water to nearby trees which in turn promotes the cooling effects of evapotranspiration and shade. Likewise, infiltration re charges aquifers upon which some cities depend for water supplies.

Although concrete grid pavements have a higher initial cost, their lower maintenance costs and their recyclability make them cost competitive with conventional paving surfaces. Their longevity and recyclability is dependent on the quality of manufacture, the integrity of the installation, and the local climate. Proper maintenance of the grass surface will also yield the ongoing benefits of less stormwater runoff and cooler temperatures. Most of all, grid lots possess the invaluable visual benefits of a park-like greenspace amenity.

6. REFERENCES

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