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DISCLAIMER

INTRODUCTION

The "Cool Pool" is a passive cooling system consisting of a shaded, evaporating roof pond which thermosiphons cool water into water-filled, metal columns (culvert pipes) located within the building living space. Figure 1 shows a schematic of the Cool Pool and test building which has been built at Living Systems located near Sacramento, California.

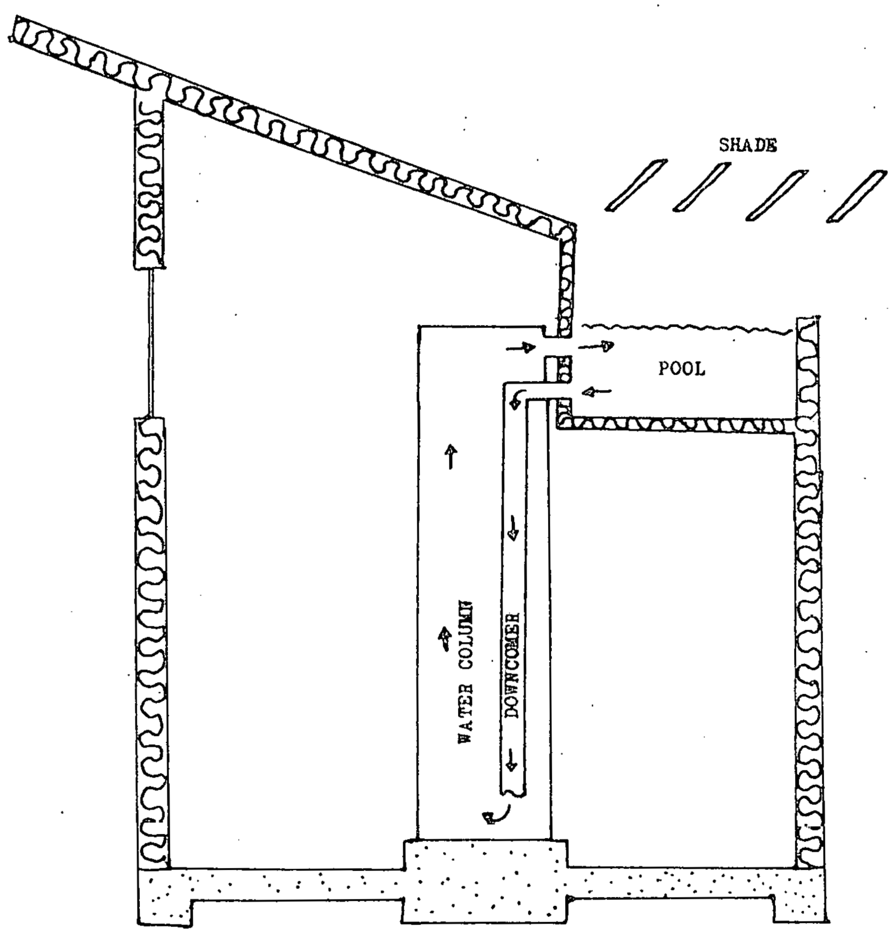

Figure 1. Cool Pool Test Building

The roof pond requires no movable insulation. A fixed shade keeps direct sunlight out of the pool but allows air movement over the pool surface. The water in the roof pond is cooled by evaporation, convection and radiation.

Because the water in the pool and downcomer is colder and denser than the water in the column a pressure difference is created and the cold water flows from the pool, through the downcomer and into the bottom of the column. The warm column water rises and flows through a connecting pipe into the pool. It is then cooled and the cycle repeats itself. The system requires no pumps.

The water column absorbs heat from the building interior primarily by convection and radiation. Since the column is radiating at a significantly lower temperature than the interior walls it plays a double role in human comfort. Not only does it cool the air by convection but it provides a heat sink to which people can radiate. Since thermal radiation is important to the cooling of people, the cold water column contributes substantially to their feelings of comfort.

During 1979-1980 Living Systems is continuing the investigation of the Cool Pool. The major tasks under the D.O.E. grant include: Control of biological organisms and debris in the roof pond and water cylinders (B.4); Development of a heat exchanger (B.5); Experimental investigation of the system's thermal performance (C.5); and development of a predictive computer simulation of the Cool Pool (C.6).

This interim report will discuss the progress made between March and June of 1979.

B.4 BIOLOGICAL ORGANISMS AND DEBRIS

Mosquitos, algae, and debris may develop in the Cool Pool. Mosquitos must be completely controlled as they are not only a nuisance but present a health hazard. Algae and debris are problems only if they obstruct the plumbing or aid in corrosion of the pool container.

Three main controls for these problems are being investigated: biological, chemical and barrier.

The biological control method is being tried in the 6'x10'x1' deep shaded Cool Pool located on the roof of the test building. This pool is now plumbed into two 8' tall 1½' diameter water cylinders which are thermosiphoning. The chemical and barrier experiments are being conducted in 14" diameter 4" deep galvanized steel pans located under a plywood shade (see Figure 2).

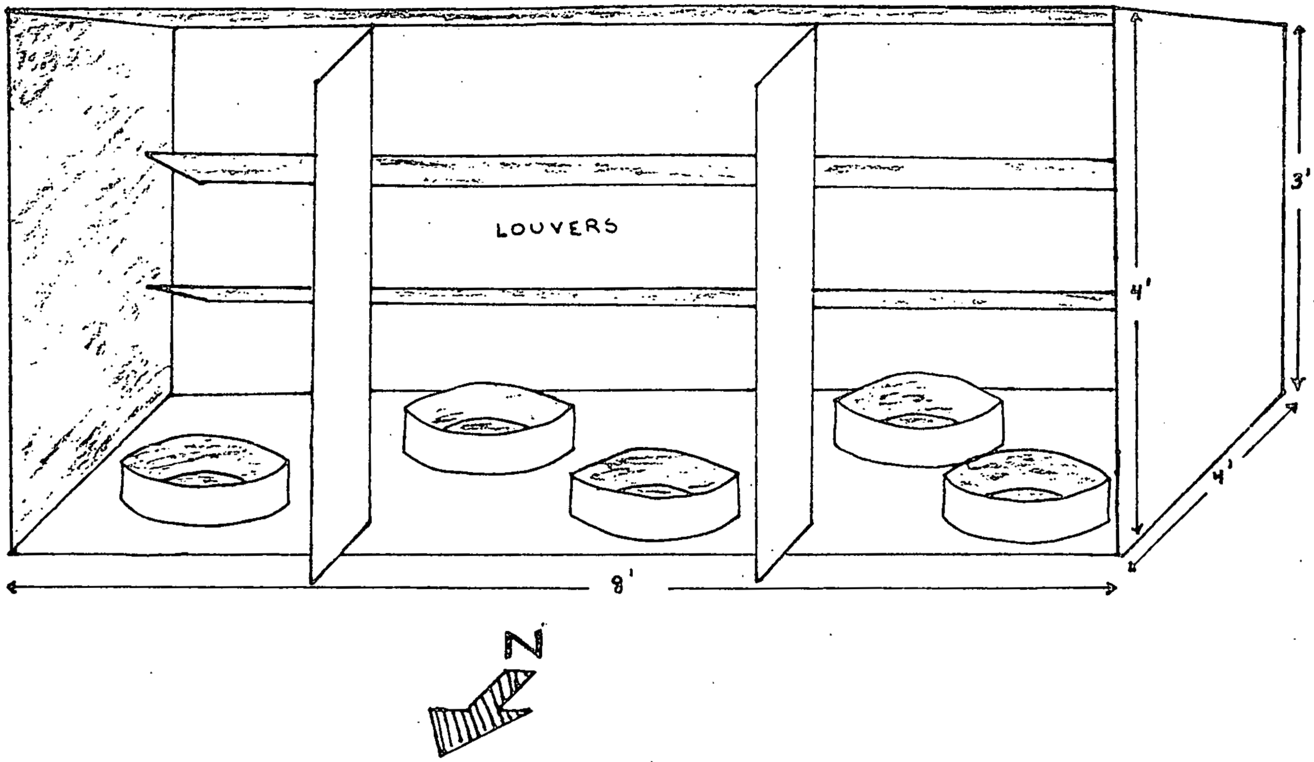

Figure 2. Biological Set-up

Biological:

Mosquito fish, Gambusia Affinis, eat mosquito larvae. They thrive in water which is between 40°F and 100°F and can even survive the winter under a layer of ice. These fish grow to be about 2 inches long. They bear live young about three times per summer.

Mosquito fish were introduced into the Cool Pool test building water on June 11, 1979. As of June 30, 1979 they are alive and no mosquitos have developed although mosquitos are present in this area.

Algae is growing in a thin layer on the Cool Pool bottom. After 2 years of operation no corrosion of the metal pan is visible under the algae and the algae is not inhibiting the flow through the pipes. It does not seem to present any problem.

Chemical

Two chemical alternatives are being investigated including Copper Sulphate and Ph control.

Copper Sulphate (also known as blue stone) is an algaecide which, in the recommended dosage (1 to 1.5 ppm), is relatively harmless to most animals including humans and livestock. It is toxic in greater concentrations. Since it does not evaporate with the water one dose should last the season. However, when the winter rains cause runoff, an overflow to the sewer system or septic tank should be provided to avoid the build-up of copper sulphate in the soil.

Copper Sulphate may control mosquitos by depriving the larvae of food. It tends to oxidize ferrous materials but as yet no corrosion of the galvanized steel container has been observed.

Agricultural Lime ($CaCo_3$) has been used to induce an alkaline Ph of about 8.3. This appears to be the maximum soluability achievable. It is hoped that this basic environment will inhibit algae growth and thus starve the mosquito larvae. Preliminary results indicate that the lime enhances corrosion.

The control pan has achieved a Ph of 8.3 from evaporation and concentration of naturally occuring salts without corrosion.

Volatile chemicals such as chlorine were rejected because the pool water would need to be constantly tested and the chemical replenished. In addition, chlorine is an oxident and corrodes steel.

Oil or kerosene is used to control mosquitos. However a coating of these substances on the water surface may also decrease evaporation and decrease the pool's ability to reject heat.

Barrier

Ordinary polyester window screening has been fastened over one test pan. The screen is located 1½ inches above the water surface and the edges are carefully sealed to the pan. Although it is possible that the mosquitos may lay their eggs through the screen, the new mosquitos will be trapped under the screen and die. During the 3 weeks the screen has been in place no larvae have been observed in the water.

Conclusion to Biological

The effectiveness of the different methods for mosquito control is currently being tested. It appears that lime aids corrosion and should not be used where it may come into contact with steel. Algae and debris do not seem to present a problem. They do not appear to enhance corrosion nor do they inhibit the thermosiphoning.

B.5 DEVELOPMENT OF A COOL POOL HEAT EXCHANGER

A sheet metal heat exchanger and vinyl water bag were studied. A discussion of the pros and cons of each method follows:

The thermosiphoning Cool Pool operates on a pressure difference of as little as 0.05 psi. This rules out the use of conventional piped heat exchangers since they introduce substantial frictional resistance and would stop the thermosiphoning. The designs shown in Figures 3 and 4 present negligible frictional resistance to the water flow.

It is important that the surface of the pool be at an equal or higher level than the top of the water cylinder so that the thermosiphoning will work properly. This presented a design problem for the rigid sheet metal heat exchanger. The solution is shown in Figure 3.

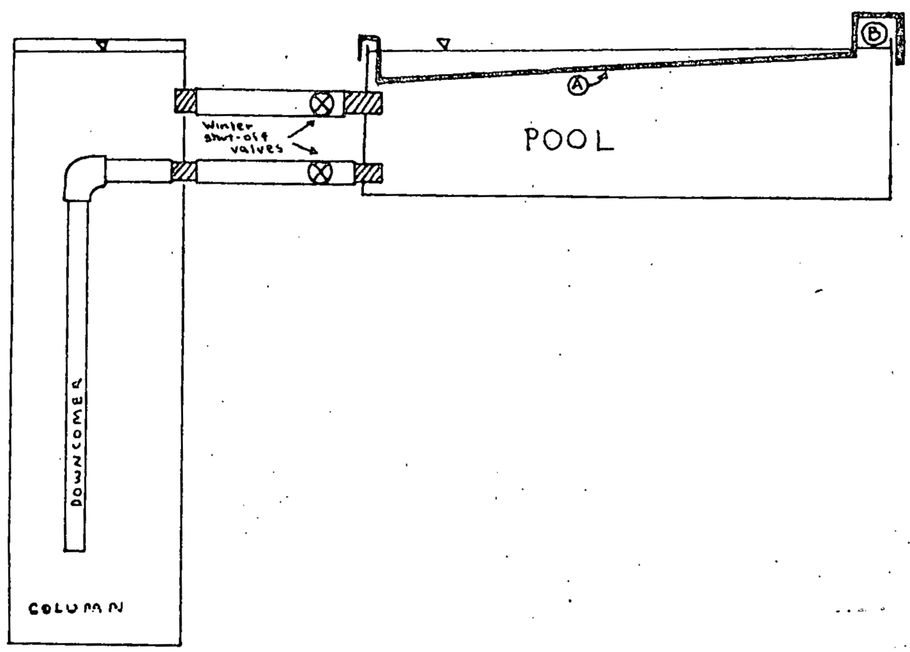

Figure 3. Metal Heat Exchanger

The sheet metal exchanger (A) is tilted slightly from horizontal so that air will not be trapped under the metal and obstruct the heat transfer from the isolated lower water to the top, evaporating water. The highest point of the system (B) contains a float valve with make up water to insure the water level remains high enough. If the water level were to drop so that there was an air gap between the lower water and the heat exchanger, cooling would be drastically reduced. Although the water under the heat exchanger is enclosed and should not need replenishing, experience has shown that a back-up system is wise. A second float valve located above the heat exchanger is necessary to replenish the evaporating water.

Figure 4 shows the vinyl waterbag heat exchanger. Since vinyl has about the same density as water the water bag completely loses its structural shape when immersed in water. This presents a problem since the vinyl may drape over the connecting pipes and obstruct the thermosiphoning. Or it may float to the pool surface, become dry and reduce the water area available for evaporation. Therefore a restraining framework must be designed for the vinyl heat exchanger.

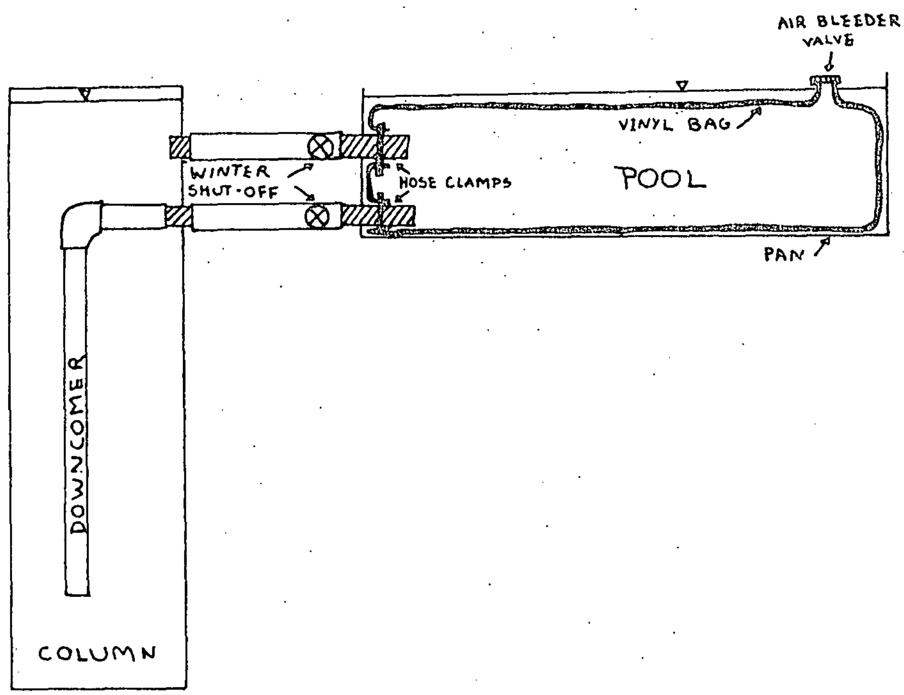

Figure 4. Vinyl Bag Heat Exchanger

Since flexible vinyl film does not affect the pressure gradient within the roof pond only one float valve (located at the free surface) is necessary. Care must be taken that the water level in the interior column remains at or below the pool's free surface. This will not be a problem unless the cylinder is over-filled initially.

A prototype water bag heat exchanger is currently being constructed by Carson Manufacturing Company in Sausalito, California and will be installed on the Cool Pool during the 1979 summer. The restraining framework is being designed.

C.5 COOL POOL SIZING EXPERIMENTS

The Fluke 2200B data logger has been hooked up to thermocouples which monitor temperatures in the test building. Temperatures monitored include 5 levels in the water column, 8 levels of interior air, 3 levels in the downcomer, ceiling and wall temperatures, pool temperature, outside dry and wet bulb (via an aspirated wet bulb thermometer using platinum resistance sensors). Net radiation over the pool is also recorded. The thermocouples were fabricated from Omega 30 guage teflon coated copper-constantan wire. The ends were welded together and coated with epoxy to prevent spurious currents from interfering with the voltage readings.

The thermocouples were calibrated against a secondary standard platinum resistance thermometer owned by the University of California at Davis. A Rosemount controlled temperature oil and ice bath was used. Results indicate that all thermocouples were uniformly biased by a maximum of .2°C at 50°C (less at lower temperatures) but that there was no detectable deviation among the thermocouples themselves.

On May 24, and May 25, 1979 the first thermosiphoning test was conducted. The thermosiphoning rate was measured by injecting vegetable dye through a rubber sleeve connecting a 4 ft. long 1½" ID transparent acrylic tube to the riser outlet. The length of time that the fastest central stream-line took to traverse the 4' tube was recorded. The flow was obviously laminar. Therefore the average velocity was determined by dividing the centerline velocity in half.

Average measured velocities were compared to theoretical velocities calculated from the relationship.

$$\rho\frac{v^2}{2}\left(f\frac{L}{d}+K\right) = \xi\gamma h_d - \xi\gamma h_c$$

where ρ = density of water

v = average velocity

f = friction factor = 64/Re

Re = Reynolds number

L/d = length ÷ diameter ratio ∿ 120

K = expansion factor (4.5 for 5 expansions)

$\Sigma\gamma h_d$ = height × density for downcomer

$\Sigma\gamma h_c$ = height × density for column (from measured temperatures)

Table I shows the experimental velocities and the calculated velocities. The maximum discrepancy was 12.6% which shows excellent agreement considering the error analysis indicates the maximum possible error in calculated velocity resulting from cumulative measurement errors could reach 20%.

READING	DGH	VCALC	VEXP	DIFF%	RATIO
1	0.091	0.0598	0.0535	11.8	0.895
2	0.067	0.0460	0.0472	-2.6	1.026
3	0.076	0.0519	0.0471	10.2	0.908
4	0.098	0.0639	0.0654	-2.2	1.023
5	0.109	0.0699	0.0702	-0.4	1.004
6	0.110	0.0710	0.0673	5.5	0.948
7	0.109	0.0702	0.0678	3.5	0.966
8	0.105	0.0684	0.0601	13.7	0.879
9	0.091	0.0608	0.0570	6.7	0.937
10	0.075	0.0514	0.0522	-1.6	1.016
11	0.077	0.0529	0.0487	8.6	0.921
12	0.085	0.0572	0.0585	-2.2	1.022
13	0.095	0.0627	0.0625	0.4	0.996
14	0.100	0.0650	0.0637	2.1	0.980
15	0.102	0.0659	0.0645	2.2	0.978
16	0.100	0.0648	0.0631	2.7	0.974
17	0.097	0.0630	0.0625	0.8	0.992
18	0.100	0.0639	0.0617	3.5	0.966
19	0.097	0.0622	0.0617	0.8	0.993
20	0.090	0.0582	0.0588	-0.9	1.010
21	0.086	0.0560	0.0560	0.1	0.999
22	0.078	0.0512	0.0536	-4.5	1.047
23	0.072	0.0480	0.0539	-11.0	1.124
24	0.065	0.0438	0.0447	-2.0	1.021
25	0.065	0.0440	0.0449	-1.9	1.019
26	0.063	0.0431	0.0484	-11.0	1.123
27	0.070	0.0475	0.0455	4.5	0.957
28	0.071	0.0482	0.0482	0.1	0.999
29	0.070	0.0475	0.0479	-0.7	1.007
30	0.074	0.0467	0.0521	-10.4	1.116
31	0.071	0.0449	0.0534	-15.9	1.189

Table I. Calculated vs. Measured Water Velocities Through 1½ Inch Pipe

C.6 PREDICTIVE COMPUTER SIMULATION

A computer model of the Cool Pool has been developed. The system was divided into ten nodes and ten first degree nonlinear differential equations were written for the heat and mass transfer processes between nodes. Figure 5 shows the nodes.

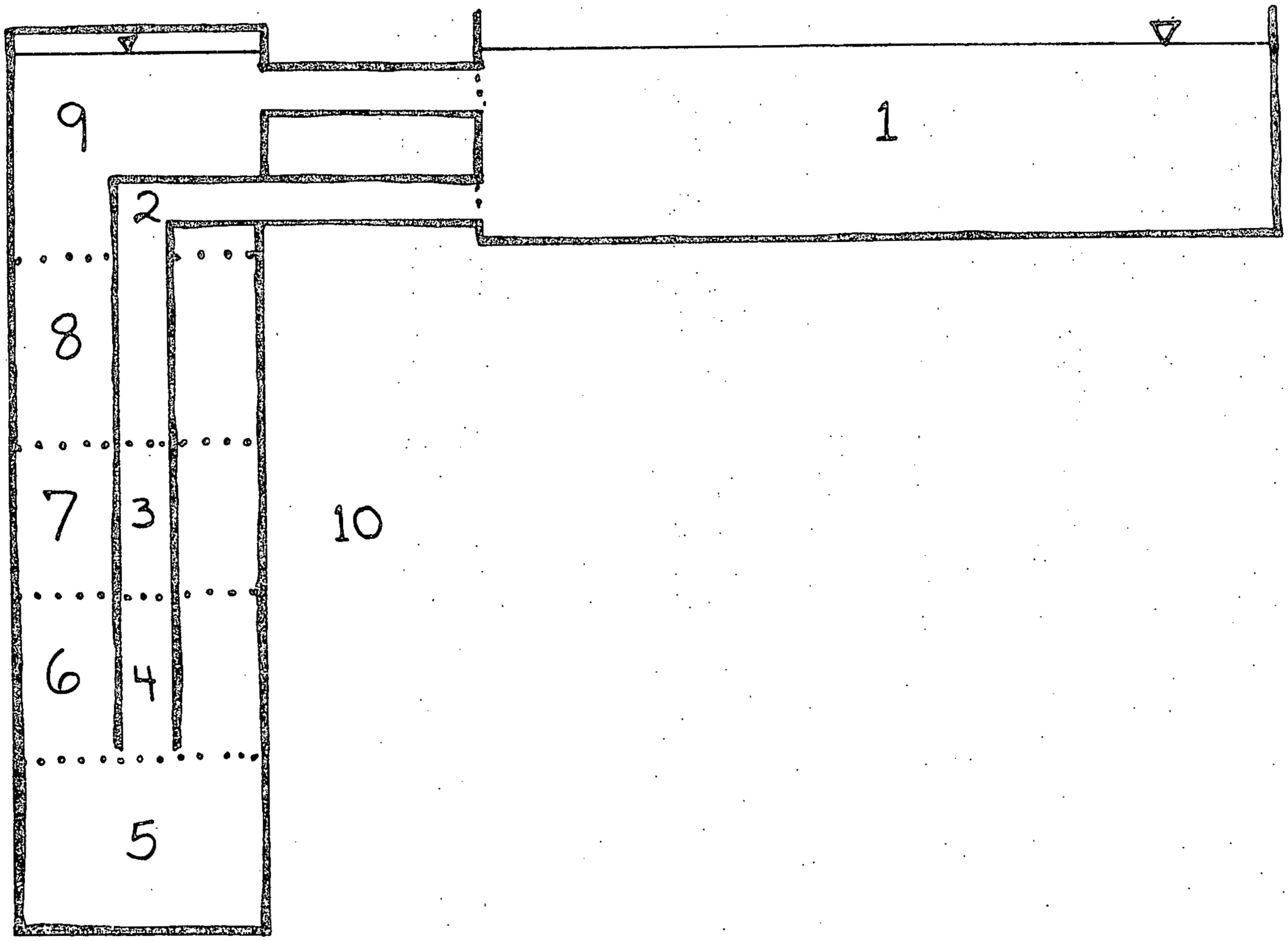

Figure 5. Nodes For Computer Simulation

Node 1 is the roof pool. The downcomer and column are divided into horizontal slices. Nodes 2, 3 and 4 are the top, middle and lower downcomer nodes. Node 5 is the lowest column slice. Nodes 6, 7 and 8 are the middle column nodes. Node 9 is the top column node. The tenth node is the interior air.

The heat transfer mechanisms described by the differential equations are these:

Node 1. The Roof Pond

A) mass flow from column top

B) mass flow to downcomer top

C) evaporation to outside air

D) convection to outside air

E) net radiation from shades and sky

Node 2 - 4. The Downcomer

A) mass flow in and out

B) conduction from water column

Node 5 - 9. The Column

A) mass flow in and out

B) conduction from downcomer

C) radiation to building interior

D) convection to interior air

Node 10. Interior Air

A) radiation from column

B) convection from column

C) building load

It is assumed that convection loops within the 1½ foot diameter water column enhance temperature stratification. To simulate this process all the water cooled by conduction from the downcomer is assumed to be delivered to the bottom of the water column. Conduction between water layers (which would weaken temperature stratification) is ignored.

<u>Sizing Program</u>

The first version of the sizing program has been developed using the following inputs and heat transfer paths.

Inputs (hourly)

net radiation into pool (experimental)
outside air temperature
outside wet bulb temperature

Parameters

building hourly heat loss coefficient
volume of water column
surface area of column
volume of roof pond
surface area of roof pond
pipe loss friction factor
surface area of downcomer
volume of downcomer
volume of building

Initialization

all node temperatures

Interim Outputs

node temperatures
velocity of water in riser
mass flow rate
net heat transfer into column from air

Results

This program models thermosiphoning and column temperatures quite well. Future work will attempt to develop an algorithm for air stratification or an alternate method of accurately predicting heat transfer into the column surface. These algorithms can then be incorporated into the computer model.

Hourly west and dry bulb climate data for different areas of the United States has been gathered and will be used for sizing the Cool Pool for the Cool Pool climatic regions.

CONCLUSION

Work has progressed rapidly during the first quarter of this project. The second quarterly report will include

- Results and conclusions from the biological testing.
- Performance evaluation of the heat exchanger.
- A comparison of simulated Cool Pool performance with the experimental data.