EVAPORATIVE ROOF COOLING
A SIMPLE SOLUTION TO CUT COOLING COSTS

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ABSTRACT

Since the "Energy Crisis" Evaporative Roof Cooling Systems have gained increased acceptance as a cost effective method to reduce the high cost of air conditioning. Documented case histories in retrofit installations show direct energy savings and paybacks from twelve to thirty months.

The main operating cost of an Evaporative Roof Cooling System is water. One thousand gallons of water, completely evaporated, will produce over 700 tons of cooling capability. Water usage seldom averages over 100 gallons per 1000 ft.^{2} of roof area per day or 10 oz. of water per 100 ft.^{2} every six minutes.

Roof Cooling Systems, when planned in new construction, return 1-1/2 times the investment the first year in equipment savings and operating costs. Roof sprays are a low cost cooling solution for warehouses, distribution centers and light manfacturing or assembly areas with light internal loads. See text "Flywheel Cooling."

INTRODUCTION

Evaporative roof cooling or "roof spray systems" were first introduced in this country in 1934. An ingenious irrigation engineer designed and installed a "system" to cool the roof of a "high-rise", three-story apartment building in Washington, D.C. Prior to the installation, the owner of the building had a problem renting the third floor apartment during the summer months due to the heat build-up in the roof that radiated through the ceiling creating discomfort for the tenants. As a result of spraying the roof, the internal temperatures dropped dramatically and the apartment stayed occupied on a year round basis.

Since that humble beginning, literally millions of square feet of roof cooling systems have been installed in industrial and commercial buildings. A "mini-boom" for roof sprays existed following World War II, when air conditioning was new and in short supply. The industrial markets of the northeast and midwest were the "cradel" of this new industry. Later this emphasis shifted to the textile industry of the southeastern United States using a more modern approach. The textile industry pioneered evaporative roof cooling as a supplement to air conditioning due primarily to the need for a critical humidity control in the process of producing fabrics. In the fifties and sixties, air conditioning became commonplace as operating costs were cheap and roof sprays were "retired".

It took the "energy crisis" of 1973 to 1974 to awaken in all Americans the need to conserve what has now become very high-cost electricity throughout the country. Many of the nation's largest corporations went to work on the problem and evaporative roof cooling has had its "rebirth" as a time-proven and cost-effective solution to reducing the heat load in buildings.

Many of these older, large corporations simply dusted off what they already knew about roof cooling from prior experience. But, by now, the old test results and data had been filed away under ancient history. A whole new generation of plant engineers and professionals were totally uninformed on the subject. Today the industry is small and limited in resources, and the reintroduction process has been slow, but is gaining momentum through established results, from satisfied users, and through informative seminars such as this.

Today, it is doubtful any plant engineer, facilities planner, or professional consultant would knowingly pass up the opportunity to reduce the load on existing air conditioning systems by 25% or more and save a comparable amount in new construction. Yet many do, simply for lack of information.

Since the recovery from the recession of 1981 to 1983, oil prices have plummeted and a false complacency has crept back into the boardroom. Energy departments have been disbanded and less importance is placed on saving energy. As an old friend remarked, "Energy has become dull and deferrable." You and I know differently. The PUC is deferring the inevitable. The power companies may have reorganized, but the rates are just as high.

BACKGROUND

Evaporation is a natural cooling process or to put it another way, it's nature's way of cooling. A roof spray system is fundamentally an evaporative cooling process. Every pound of water that is evaporated absorbs approximately 1000 Btu

Proceedings of the Second Symposium on Improving Building Systems in Hot and Humid Climates, College Station, TX, September 24-26, 1985

of heat. With at least 85% efficiency, a roof temperature within eight to ten degrees of wet bulb temperature can be maintained. During a typical summer cooling season in the south, this translates to a 40°F to 60°F reduction in the roof surface temperature, which is a substantial amount of heat transferred.

During the long hot summer months, it is not unusual to have a dry roof temperature as high as 160°F and higher in the case of dark colored roofs. With a wet bulb of 80°F, this roof temperature can be lowered to 90°F with an evaporative roof cooling system.

Roof cooling is not a substitute for air conditioning and should never be considered as such. Evaporative roof cooling systems perform one specific job; they dissipate the solar heat load on the roof. They cannot reduce high internal loads. They are most effective when a building has a large roof area in proportion to exposed walls and sensible to total heat ratios are high.

In this business, it's not the amount of water you apply but the amount of water you evaporate. The objective of a well designed evaporative roof cooling system is to spray as much water on the roof as will evaporate and not one drop more. If there is an excessive quantity of water, and it stands on the roof, the cooling action is less efficient and the roof temperature will actually rise in those areas. Uniform distribution of the water and complete coverage is essential. This is difficult to achieve the lawn sprinkler type "heads" that by necessity must rely on multiple overlaps to insure coverage from a 360 degree spray pattern. Careful equipment selection and the expertise of the designer are the fool proof criteria to achieve optimum results.

The American Society of Heating & Ventilating Engineers (forerunners of ASHRAE) conducted extensive tests in 1939 on evaporative roof cooling and the results showed as much as 87% reduction in peak heat penetration using sprays versus dry roof and a 92% reduction in average heat penetration throughout the course of the day. Now data for the design of roof sprays have been published in the ASHRAE Guide and Data Book.

In Dr. John Yellott's presentation (2) on evaporative roof cooling, his study concluded that water is by far the most economical refrigerant, since one gallon of water represents about <u>8650</u> Btu of cooling capability and 1000 gallons <u>used</u> completely will produce somewhat more than 700 tons of refrigeration. Compare your local water rate cost per 1000 gallons to the current kWh cost and you will quickly agree with what Yellott said nineteen years ago.

PRINCIPLE OF OPERATION

The roof is accurately measured, noting obstructions, elevation changes and type of roof surface material. The roof need not be flat as with proper design methods and equipment, pitched roofs can be effectively cooled. Excellent results have been achieved in metal buildings.

The hydraulic variables, pressure and supply, must be determined. Usually 45 GPM @ 50 psig is required for a 100,000 square foot roof area. With the variables determined, the designer then divides the roof into zones. A grid of copper spray tubing is established at 16 ft. to 18 ft. on center. With a design pressure of 25 psi, this will create an effective spray radius of 10 ft. and insure complete coverage. All supply piping and spray laterals are supported at 5 ft. intervals by cementing redwood blocks to the surface. No roof penetrations are necessary with the exception of very large roof areas, and this is done by a competent roofing contractor. Oversize copper tube straps are utilized to allow for normal expansion and contraction. They are nailed to the blocks with aluminum nails.

A microprocessor controller, which is programmable by the user, is set up for multiple time of day programs with a completely variable on/off time for the spray lines. Usually, this is ten to thirty seconds "on-time" per zone, and an "off-time" of three to eight minutes depending on job conditions. The operation of the system is sequential and the whole system is activated by a roof thermostat set for a heat rise condition of 90°F. When the roof temperature falls below the set point, the system will automatically shut itself off. Here again the skill and experience of the designer are important to insure that only the thin film of water needed to evaporate completely between cycles is being applied.

In certain cases, waste water can be utilized if it is relatively clean. We have several installations that are operating with waste process water. The water temperature does not materially affect the evaporative cooling process. Dr. Yellott tested 120°F water versus 80°F and it only made one degree difference in the roof temperature as evaporation took place. Water usage will naturally fluctuate with the climate. A peak volume would be 150 gallons per 1,000 square feet per day. We have several systems with separate water meters that allow the user to pay for water only without sewer charges. From these records of usage and based on 180 to 200 operating days, the yearly average will work out to 100 gallons per 1000 square feet per day. This is essentially the only operating cost of an evaporative roof cooling system save the minimal amount of power for the timer.

Maintenance of a roof cooling system consists of draining it in the winter. Good design will provide for drain valves in the main supply lines and at the end of each spray line. Large systems can usually be purged with compressed air. In the springtime, when the system is activated for the season, these same drain valves are utilized to flush the system of any sediments. Good equipment will feature manual override; of the operating valves. Self-cleaning spray orifices eliminate clogging problems. The only attention required to the system is periodic inspection during the season. Annual maintenance cost will seldom exceed .005% per square foot. Maintenance service contracts are usually available through qualified local distributors.

The only moving parts in our present system are the valves. They can be repaired or replaced without removing the valve body from the copper line.

AIR CONDITIONING SAVINGS

Numerous documented case histories have established paybacks from 12 to 30 months when evaporative roof cooling has been used to reduce the air conditioning load. Annual A.C. run times vary as do operating costs from one locale to another.

To help you in determining an estimate of savings that can be expected, let's refer to the simple example on The Internal BTU Heat Relief-Dry vs. Damp Roof chart (Table I). This is an example of a typical older building and let's assume it is being cooled with old DX type units that are usually installed on the roof. During the season, 1.5 kW per ton is a conservative estimate for this type of equipment.

Calculations for the peak summer cooling period are shown below. Note that this peak period can affect demand charges.

PEAK DEMAND CHARGE REDUCTION (Fig. 1)

Assume \$5.00 per kW and a 100% ratchet:

138 tons X 1.5 kW/ton = 207 kW saved
207 kW X \$5/kW X 12 months = \$12,420 annual savings

Depending on the demand rate and ratchet figure, it may require the first year of operation to fully realize the savings; but the effect of reducing the summer peak load is obvious.

AVERAGE ENERGY CONSUMPTION REDUCTION (Fig. 1)

Assume \$.04 per kWh (direct energy cost and fuel adjustment) and 2,000 annual operating hours:

79 tons X 1.5 kW/ton X 2,000 hrs. = 237,000 kWh saved per year

237,000 kWh X \$.04/kWh = \$9,480 saved per year

WATER COST

At \$1.00 per 1,000 gallons and using the 100 gallon per 1,000 square feet per hour, our example installation evaporates 10,300 gallons per day or \$10.30 per day for 180 days = \$1,854.

Summary of Cost Savings

Demand Charge Savings	\$12,420
Direct Energy Savings	9,480
Subtotal Savings	\$21,900
Less Water Cost	(1,854)
Less Maintenance 1st Year	(515)
Annual Savings	\$19,531

With a current installed evaporative roof cooling system with costs of \$36,000, the straight payback is 22 months at current rates.

The life cycle cost of an all copper and brass evaporative roof cooling system is exceptional and easily equals the life of the building with normal service.

TABLE I

Internal BTU Heat Relief - Dry vs. Damp Roof

Shown below is the heat relief provided by FAN-JET Solar Roof Cooling in Btu per square foot of roof surface at various "U" factors and roof temperatures.

Roof "U" Factor	Roof Surface Temperature 170°	160°	150°	140°	130°	120°
.05	4.0	3.5	3.0	2.5	2.0	1.5
.07	5.6	4.9	4.2	3.5	2.8	2.1
.10	8.0	7.0	6.0	5.0	4.0	3.0
.13	10.4	9.1	7.8	6.5	5.2	3.9
.15	12.0	10.5	9.0	7.5	6.0	4.5
.17	13.6	11.9	10.2	8.5	6.8	5.1
.19	15.2	13.3	11.4	9.5	7.6	5.7
.21	16.8	14.7	12.6	10.5	8.4	6.3
.23	18.4	16.1	13.8	11.5	9.2	6.9
.25	20.0	17.5	15.0	12.5	10.0	7.5
.27	21.6	18.9	16.2	13.5	10.8	8.1
.30	24.0	21.0	18.0	15.0	12.0	9.0

The above table is based on the following formula:

$$[(T1-T3) \times U] - [(T2-T3) \times U] = Y$$

Y = Relief provided in BTU's per square foot per hour.

U = Heat transmission coefficient of the roof.

T1 = Roof surface temperature without FAN-JET.

T2 = Roof surface temperature with FAN-JET (90°F).

T3 = Design interior temperature of the building (78°F).

Example of How to Use:

A 103,000 square foot building with built up tar and gravel roof on a steel deck with 1" insulation .23 "U" factor (ASHRAE).

Peak Demand

160° roof temperature with a .23 "U" factor = 16.1 Btu relief per square foot per hour X 103,000 square feet = 1,658,300 Btuh ÷ 12,000 Btu (Ton AC) = 138 tons reduction in air conditioning.

Average Reduction

Average roof temperature 130° with a .23 "U" factor = 9.2 Btu relief per hour X 103,000 square feet = 947,600 Btu ÷ 12,000 Btu (Ton AC) = 79 tons reduction in air conditioning.

APPLICATIONS IN NON-AIR CONDITIONED BUILDINGS

While this presentation deals primarily with air conditioned buildings, it is well to keep in mind that considerable comfort cooling can also be realized in non-air conditioned buildings. Documented case histories, which can be verified, have shown reductions of 10°F to 15°F in working level temperatures with evaporative roof cooling and complete elimination of the effect of radiant heat on workers.

Evaporative roof cooling combined with planned ventilation have achieved results of 20°F to 22°F cooler interior building temperatures, especially in warehouses and distribution centers where the internal load is not too great. This technique is called "Flywheel Cooling". We have installations in Texas where the building interior temperatures did not exceed 84°F while the outside ambient temperature levels were at 105°F to 106°F. By not having to air condition these buildings, considerable energy has been saved. Even in applications of this type that are presently air conditioned, it would certainly be worthwhile to pursue this approach and duty cycle the air conditioning in the afternoon if necessary.

Several of our customers have heat sensitive products and elevated temperatures, of 90°F or greater, shorten shelf life and cause spoilage. The "Flywheel Cooling" method has solved their summer storage problems, at a fraction of the cost of refrigeration.

HIGH-HUMIDITY CONDITIONS

One of the most frequently asked questions is how can evaporative roof cooling be effective in an area with high relative humidity? Florida has summer design conditions of 91°F Dry Bulb with a 78°F Wet Bulb. This equals 60% relative humidity. With only a modest rise in the Dry Bulb temperature to 120°F and the same 78°F Wet Bulb, we now have only 30% relative humidity! We have many successful installations in Florida.

The same solar radiation that heats large, dry roof surfaces is now being absorbed by the molecules of moisture and the evaporation takes place rapidly. Radiation has a major effect on evaporation along with wind speed. Most roofs will have an average height of twenty feet or more from ground level, and the surface winds are not obstructed. For those of you who do not spend a lot of time on the roof, you can relate this to how quickly the streets and parkings lots dry off after a rain in Houston, New Orleans, and anywhere along the Gulf Coast. It is also interesting to note that there is really very little change or adjustments for cooling towers from one area to another, to compensate for the rate of evaporation.

If you remember the "old lister bag", you will recall how much cooler the water was when the bag was left outdoors exposed to full sunlight as opposed to when you hung it in the shade. Believe me, there is very little shade on most industrial and commercial roofs.

The combination of high solar energy and air movement do create considerable evaporation on large dry surfaces. The evaporative roof cooling system will use less water in Houston than El Paso. The new programmable microprocessor can compensate for this by programming shorter spray "on-time" and longer "off-time" (drying time) in the morning when the wet bulb is higher and then shorten the cycle for the afternoon as the drying time decreases.

ROOF PROTECTION

The first reaction to roof spray cooling and putting water on the roof is usually negative. However, we have found that by keeping the roof at a relatively cool 90°F versus having the temperature climb to 160°F, evaporative roof cooling can actually double or triple the life expectancy of the roof.

There are three major factors that destroy a roof. They are:

1. Blisters. Blisters form when the roof temperatures reach 150°F to 160°F. The gravel falls off the blister and this allows the ultra violet rays of the sun to directly attack the asphalt. This causes the oils to dry out, cracking occurs, and roof problems begin.

2. Expansion and Contraction. During a 24-hour day, the temperature fluctuates from 160°F during the day to a cool 75° at night. This expansion and contraction can pull the flashing away from the parapet walls around roof-mounted fans or air-handling units; however, by holding a constant temperature with very little fluctuation, the expansion and contraction is virtually eliminated.

3. Thermal Shock. When the roof temperatures rise to 160°F and an afternoon shower comes through the area, we have tests that show that the temperature will drop by as much as 58 degrees in less than 15 minutes. Since the roof is comprised of different layers of paper, felts, insulation and tar and gravel, the contraction is not equal throughout the roof, thus, producing a shearing action which can actually tear the roof open and create maintenance problems. By maintaining the roof temperature at or below 90°, thermal shock is virtually eliminated.

In a recent paper presented by Mr. Jack Reed, (4) he stated that there were far fewer leaks in spite of adding many more roof penetrations over a period of fifteen months. Today, four years later, he reports no leaks in his fourteen year old roof.

CONCLUSIONS

Evaporative roof cooling systems, having had a successful history in the 30's and 40's, are making a come back in the field of Industrial Air Conditioning as one of the most cost effective methods to reduce cooling costs.

Microprocessor timers are giving better control of spray timing to compensate for climatic conditions and furnish greater efficiency.

Roof Cooling can eliminate up to 85% of the roof air conditioning load and makes a large cooling panel out of the ceiling instead of a heat radiator.

Retrofitting of older buildings is a prime application for evaporative roof cooling.

When additional tonnage is needed due to plant expansion, evaporative roof cooling, by reducing the roof load, can provide the additional cooling requirements at a fraction of the cost of installing new equipment.

New construction with a R10 roof can return the cost of the evaporative roof cooling system 1-1/2 times through equipment savings, and lowering operating cost on a continuing basis.

Heat stress is reduced in non-air conditioned buildings resulting in marked increases in productivity while also providing safe storage temperatures for materials. Today's management is more aware of the high cost of lost productivity in hot buildings.

Roof Cooling is effective in humid climates with proper design and control.

Roof Cooling protects and extends roof life by keeping the roof consistently cooler and preventing thermal shock.

Evaporative roof cooling can show a payback of twelve to thirty months.

One thousand gallons of water completely evaporated will produce over 700 tons of cooling capability.

REFERENCES

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