Löf Energy Systems, Inc.

720 Corporate Circle, Unit R
Golden, CO 80401
(303) 279-8463

SYSTEM FOR REDUCING HEAT LOSSES FROM INDOOR SWIMMING POOLS BY USE OF AUTOMATIC COVERS

FINAL REPORT

by

LÖF ENERGY SYSTEMS, INC., GRANTEE

for period from October 1, 1993 to September 30, 1995

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I EXECUTIVE SUMMARY

This final report is an account of the principal activities of Lof Energy Systems, Inc. in a two-year project funded by the Energy Related Inventions Program (ERIP) of the U. S. Department of Energy. The primary objective has been the development of a fully practical and economical system for saving energy in indoor swimming pools by use of motorized covers. The goal is wide-spread use of a fully developed product in institutional swimming pools.

Four major tasks, depicted in the accompanying Performance Schedule (Figure 1), have been completed, and one other has been initiated and its completion committed. Principal accomplishments have been the selection and improvement of cover materials and designs (Task 1), lengthening and strengthening of reels and improvements in motorized components and their control (Task 2), design and installation of pool covers in full scale demonstration and evaluation of fully developed commercial system (Task 4), preparation and dissemination of manuals and reports, finalization of arrangements for Underwriters Laboratory certification of products (Task 3), and final report preparation and submission (Task 5). Of greatest significance has been the successful demonstration of the fully developed system and the verification and reporting by an energy consultant of the large savings resulting from pool cover use.

Completion of the project has required exceptional commitment and dedication of all the participants. Only the foresight and perseverance of Lance Lof, company founder and first director of the project, made possible the establishment of the DOE-ERIP-LESI grant. His death in 1994 made project continuance uncertain, but that deterrent was overcome by the decisive action of Larry Lof to continue the work under his direction. That decision proved necessary to the successful completion of the project and the commercialization of the resulting product.

Probably the best evidence of success of the DOE-ERIP project in advancing this invention to a commercial stage is its acceptance for sale by the Lincoln Equipment Company, a national distributor of swimming pool supplies and equipment. A copy of the relevant page in the Lincoln catalog is included in this report as Annex A. Representatives of that company now offer Lof motorized pool cover systems to their pool owner customers.

In addition to the plans for securing UL certification, the company expects to continue making design improvements that can increase system reliability, durability, and cost-effectiveness. Greater sales volume resulting from the completed development program is expected to make it possible for the company to finance those efforts.

Figure 1

LÖF ENERGY SYSTEMS, INC. **FINAL PERFORMANCE SCHEDULE**

FINAL SCHEDULE-REVISION 7
 SEPTEMBER 30, 1995

II PROJECT ACTIVITIES AND RESULTS

In the course of the 24-month project, three principal activities have been involved: (1) product improvements, (2) demonstration and testing of improved system, and (3) dissemination of results. Five progress reports covering various periods during the first 18 months of the project have been submitted to DOE. They contain reports of the work in those three areas, and references to those reports can be made for results not repeated in detail here.

A. Product Improvements

1. Improved Cover Materials and Design

Water absorption and penetration tests on several types of woven polyethylene fabrics and foam-laminated fabrics were conducted. Samples of these materials were fabricated into one full-size pool cover, 15 ft. x 60 ft., by use of the previously adopted sewing operations. That cover was then deployed on a swimming pool and the characteristics of each section were observed and compared in a series of daily covering and uncovering cycles.

Superior performance was observed with a woven polyethylene fabric (Takashima USA, Inc.) specified as 1000/D, 10x10, 30x30 microns, 3.88 oz./sq.yd., 148 lbs. vertical and 132 lbs. horizontal tensile strength; elongation 17% warp, 15% weft; tear strength 28 lbs. warp, 24 lbs. weft.

Among foam-laminated fabrics, none proved adequately resistant to water absorption within the thin, 1/8-inch layer. It has therefore been concluded that insulated (foam) covers do not provide resistance to heat loss from an indoor pool surface that is appreciably greater than provided by the single-layer evaporation barrier.

It was also concluded that the joining of fabric sections to produce a complete cover is best accomplished by sewing rather than by heat sealing, and that enclosures and sleeves for reinforcements (cover stays, side stiffeners, and edge ropes) should also be provided by sewing.

Several cover edge designs were tested for their ability to prevent water overflow onto the cover and for their influence on the regularity and uniformity of the roll of cover being wound onto the reel. Previously used continuous 1/4-inch rope in hems along the cover edges was replaced, in one alternate design, by continuous 6-inch to 8-inch strips of laminated foam cover material sewn adjacent to both edges of the cover. Preliminary results were encouraging, but water absorption in the 1/8-inch layer of foam resulted in its non-uniform thickness at the two ends of the cover roll when being retrieved. Irregular and

excessive wandering ("telescoping") of the stored portion of the cover resulted.

The most satisfactory and dependable design, subsequently adopted, employs 1/4-inch solid core polypropylene braided rope sewn into a hem at the cover edges, and a cover-thickening strip of foam cover material sewn to the cover along its mid-line. An 8-inch strip is sewn to the cover for a 25-foot distance from the reel end of the cover, followed by a 4-inch wide strip on the next 25-foot length. The ropes in the cover hems are interrupted at several points to prevent "draw-string" effects and wrinkling of the cover.

This thickening of the middle of the cover roll has the beneficial effect of centering most of the traction force and avoiding occasional excessive pulling or tugging of one of the cover edges. Differences in diameter of the cover roll at its two ends thus have less influence on the overall uniformity of the roll on the reel.

Also adopted are cover design improvements comprising (1) pockets or sleeves for stays and stiffeners, one end of which is provided with a fabric flap which effectively closes the sleeve but which permits insertion of the stiffener during installation of the covers, (2) transparent plastic sheet (a tongue or leader) connecting the cover to the reel, thereby permitting better visibility and lighting in the deck area when the cover is on the pool, (3) broadened ends of tubular batten strips to reduce risk of their penetrating the ends of sleeves which contain them, (4) improved tow-bar bouyancy and reduced water "scooping" onto cover during deployment by use of rigid foam pipe insulation held around the tow-bar by C-shaped aluminum clips.

The foregoing developments and improvements of the pool cover materials, design, and fabrication met the objectives of Task 1 of the project.

2. Improved Mechanical and Electrical System

The principal objective of the project is to make the changes in design and operation of the invention which are necessary for advancing the concept to a fully commercial status. That objective has been achieved primarily by developing a number of important mechanical and electrical improvements that have been incorporated in systems being manufactured and installed in large indoor swimming pools.

(1) Cover reel lengthened to 24 feet and guide spindle made optional

Design, construction, and testing of cover reels lengthened to 24 feet provide the means for deploying covers up to 22 1/2 feet

wide. Reels and guide spindles of four-inch and five-inch aluminum construction tubing, 0.012 wall thickness, have been successfully tested in pools 75 feet long. In one installation, a guide spindle was not used with the reel, and in several others, the covers passed over the freely rotating guide spindle tube prior to being wound onto the storage reel. Alignment of the cover on the reel without a guide spindle is satisfactory, but not as smooth and regular as on systems with guide spindles. A decision on discontinuing the guide spindle has not been finally made.

To accomodate the increased weight and size of the lengthened reel and wider cover, thicker aluminum sheet is used in the motor box, power is increased from 1/3 HP to 1/2 HP, a larger speed reducer is used, and stainless steel reel shafts are increased from 3/4 to one inch diameter.

(2) Improved rope-tensioning brake

Tension is necessary to maintain the elevated position of the tow-rope high above the water surface during periods of pool use. Since the rope spool is free to turn when the cover is on the reel, rotation of the spool must be resisted during those periods. The resistive force must be adjustable, and retention of the adjusted setting is essential.

One design involves an improvement in the previously used system employing a narrow belt or cord pressing against the bottom of the groove in a V-belt sheave bolted to one side of the rope spool. An extension spring and adjustable turnbuckle have previously been used to apply suitable pressure of the brake band against the sheave. Design improvement has involved use of a narrow strip of conventional brake lining, a metal strip to support the brake, a heavier duty spring, and a threaded rod adjusted by a knob conveniently located below the bottom of the motor box to change spring tension. The spring provides considerably more resistance to spool rotation in one direction than in the other, as is desired. Shop testing and initial operation in a full-scale pool installation have been successful.

An entirely new brake design has been used in numerous pool cover systems recently installed. The same bolted sheave is used in conjunction with a short (2-inch) length of V-belt material bolted to a hinged arm. As rope is pulled off the spool, during cover retrieval, rotation of the spool causes the V-belt piece to wedge into the sheave groove, providing suitable frictional resistance to rotation. The wedging position is maintained during the period the pool is uncovered. When the cover is returned to the pool, rotation of the spool in the opposite direction lifts the wedge from the sheave groove and reduces the frictional drag. Adjustment of the braking pressure is provided by turning a threaded rod projecting from the bottom of the motor box. The upper end of the rod provides a "stop", or limit, to the amount of wedging pressure the V-belt can exert.

Although the V-belt brake design has been successfully used in numerous installed systems, it is more expensive than the brake-band design, and the choice for on-going production and use will depend on results of additional experience with both types. Also investigated and tested was another braking system that proved unsatisfactory. To provide rotational resistance to the rope spool when rotating in one direction, but not when rotating in the opposite direction, an electric solenoid was coupled to the brake band and extension spring. The desired spring tension and frictional drag were obtained when needed. The solenoid was actuated by the control switch, providing rotational resistance to the rope spool when retrieving and storing the cover, and eliminating frictional drag in the opposite direction. Although satisfactory braking action was obtained, excessive noise and vibration was caused by the solenoid action, and this system was therefore rejected in favor of the other improved systems.

(3) Operating system employing 24-volt control

Motors in pool cover systems installed prior to the design improvements made in this project were operated by drum switches at line voltage, 110 volts. This system required approved electric wiring in conduits extending from wall-mounted switching stations to the distant overhead motors. To reduce installation costs and also to enhance electrical safety, the system was redesigned to employ low voltage (24 volts) switches and relay circuits to control the operation of the 110-volt reversing motors. All control equipment except the double-throw rocker switch is mounted in the elevated motor box, accessible only to installer and maintenance personnel. Light gauge conductors, similar to telephone wiring, are installed from switch station to motor box without conduit or the service of an electrician. Wiring diagrams of the new system are shown in the accompanying Figure 2.

Another safety feature developed in the course of the project is the replacement of "maintained" electric control switches with the "momentary" type. The control lever in the previously used 110-volt drum switch has three positions, up, down, and off. The lever naturally rests and remains in each position until physically moved to another. A careless operator may therefore fail to stop cover movement in the event of accidental obstruction or other hazard. To minimize that risk, the drum switches were modified by removal of the holding device, thereby requiring the control lever to be continually held in the up or down position throughout cover movement. On release, the lever returns to the off position by itself.

The same type of momentary action is provided by the rocker switch in the 24-volt design, continuous finger pressure being required to maintain cover movement. On release, the switch moves instantly to the off position.

(4) Automatic motor shut-off by photoelectric sensor

Several designs and strategies were developed for employing a photoelectric cell to turn off the motor and terminate cover movement. The initial objective was for the operations to be automatically stopped without human action. After starting deployment or retrieval of the cover, the operator could leave the maintained switch unattended. When the cover reached a pre-established position, a photoelectric cell was actuated by an infra-red signal reflected from a faceted mirror mounted behind the cover and transmitted through a transparent plastic window in the cover. This action caused either an immediate interruption of power to the motor or it initiated a short delay, a few seconds, to permit limited further cover movement before motor shut-off. Suitable relays and delay elements in the motor box completed the design.

Numerous systems of this type were installed, but several operating problems were experienced. Transparency of window areas sometimes was reduced by exposure to pool water and chemicals, preventing adequate transmission of photocell signals. Occasional spurious reflections occurred from bright spots, possibly water droplets, on the cover, and through small holes or thin spots in the cover. Misalignment of photocells and reflectors sometimes resulted from accidental contact with the cover or tow-bar. Failures of photocells also occurred, possibly because of high humidity levels in the natatorium atmosphere. And, as indicated in the foregoing sub-section, the lack of operator attention permitted by use of a maintained type of control switch posed unacceptable risks of accidents.

To minimize the problems experienced with automatic photocell shut-off, several design changes were made. Of primary importance was the replacement of maintained switches with momentary type switches in the control enclosure, as previously described. Along with this measure, photocell control action was modified. Transparent plastic windows in the cover were replaced by highly reflective self-adhering tapes affixed to the cover surface. This improvement allowed removal of the awkwardly positioned mirror support arm or bracket in front of the reel and eliminated problems with faulty reflections and poor transmission of control signals. Reflective tape is applied to the cover near the reel. No tape is used on the cover near the tow-bar because exposure to water would risk deterioration and loss of adhesion, which would adversely affect performance. The need for photocell action on cover retrieval, as the tow-bar nears the reel, was eliminated by the use of a small obstruction ("stop-ball") on the tow-rope which enters one of the return pulleys on the natatorium wall opposite the reel. The tow-rope and cover are then immediately prevented from further movement. A torque-limiting clutch on the reel drive shaft then permits slippage of the retrieval mechanism until the operator releases the actuating switch at the control station.

During cover deployment, when the tow-bar reaches the end of the pool opposite the reel, a second stop-ball enters the other rope-return pulley, immediately stopping movement of the tow-rope and tow-bar. A torque-limiting clutch on the rope spool shaft permits further motor operation to unwind additional fabric from the reel to cover a few feet of water surface near the end of the pool under the reel. Reflective tape then enters the view field of the photocell, actuating the cell and a relay to shut off power to the motor. Observing that all component movement has stopped, the operator then releases the control switch. So that the motor can be restarted to deploy the cover even though reflective tape is in view of the photocell, an on-delay electric element prevents photocell actuation for a few seconds after the switch is operated, thereby allowing movement of the reflective material away from the photocell field of view.

The photocell control design finally adopted employs all the features in the foregoing description, modified as necessary for 24-volt control circuitry. Also selected for regular use is a photoelectric cell from another manufacturer, no failures of which have been encountered. The accompanying electrical diagrams (Fig. 2) show the details of design and construction. Highly reliable operation has been achieved in all installations.

(5) Automatic motor shut-off by stop-bars and micro switches

Lack of complete reliability of the photocell automatic shut-off system described above led to the design, testing, and trial installation of a system of electro-mechanical switches to reach the same objective. The tow-rope passes to and from the rope spool between two horizontal movable rods separated vertically by about one-half inch. Two stop-balls at suitable positions on the tow-rope press against the rods, inward or outward, slightly moving the rod holder against the lever arms of two limit switches (micro-switches), which make or break 24-volt electric circuits actuating motor relays. The accompanying diagram (Fig. 3) shows the principal features of this design.

Provided that switches, rod assembly, and stop-balls are securely mounted and accurately positioned, this system is highly reliable. The components are less costly than photocells, but higher costs of fabrication eliminate significant economic differences. If maintained-type of switches were used, automatic shut-off of motor power by stop-switches in both directions of cover movement would be an advantage over the lack of automatic motor shut-off by the photocell at the end of cover retrieval. However, use of momentary switches essentially nullifies the benefit of that feature.

A side-by-side installation of these two types of automatic power shut-off systems at the Skyland Recreation Center provides additional operating data on which final choice may be based. At

Figure 3 24-volt Stop Switch Control System

present, the photocell system is being employed in new commercial installations.

(6) Cover usage meter

Knowledge of the regularity and duration of cover use in an institutional swimming pool is of importance in several ways. If actual energy savings are substantially less than predicted, determination of the cause and its correction can be highly advantageous. Improper ventilation practices, faulty instruments and data, inefficient heating equipment, erroneous fuel metering, excessive leaks and losses are some of the possibilities. Duration of pool cover use is a critical factor in the analysis, and one which should be measured, not estimated or simply claimed.

Another benefit of a cover use meter is in the verification of pool employee practices and statements. Pool schedules often result in opening and closing swimming periods at times when management personnel are absent. Careless, unsupervised employees may falsely claim covers were used when, in fact, they were not.

To aid in fiscal management and to assure energy savings in covered pools, a pool cover time-clock or meter has been designed and successfully tested. An odometer-type digital hour counter is mounted in the switch box enclosure or at some other location. It is connected to one of the cover deployment switches and to relays and on-delay components so that whenever the cover is on the pool, the timer runs. When the cover is removed, the timer stops, leaving the indicated hours of coverage on the meter. Periodic reading of the dials shows the cover usage duration.

As a protection against faulty metering, delay elements are incorporated which permit up and down cover adjustments before timing is initiated or terminated. The cover operators and pool managers can therefore be assured that the meter indication is completely valid.

If desired, the meter can be located in the motor box, out of view except by service personnel. If located in the switch control station, only one wire in addition to the three employed for motor switching is needed between motor box and wall switch. Typical communication cable, with three insulated conductors and a ground wire, is conveniently employed.

(7) Drive-chain tensioning and adjustment device

An improvement has been made in the means for adjusting pillow blocks supporting the rope spool shaft so that the proper tension is provided to the roller chain between sprockets on the motor drive shaft and the rope spool shaft. Shop assembly of those components has previously required temporary forcing of a tapered wooden block between the rope spool and the top of the speed

reducer, to press the rope spool upward to tighten the roller chain. Bolts and nuts securing the two pillow blocks to the sides of the motor box were then tightened, and the wood block removed. Although reasonably satisfactory in the assembly shop, this procedure was difficult to implement in a natatorium when chain adjustment was needed.

The improved design involves mounting a 1/2-inch x 2-inch aluminum cylindrical cam on the lower bolt of one or both pillow blocks, the bolt hole being off center. A recess in the cylinder rim for a screwdriver tip permits upward rotation of the cam to press it against the lower side of the pillow block housing, thereby lifting it, the spool shaft, and the chain sprocket. When the chain has been adequately tightened, nuts on the upper and lower pillow block bolts are tightened. To readjust, nuts on the pillow block mounting bolts are loosened, the cam is rotated up or down, and the pillow block bolts and nuts retightened. This system is a simple, and excellent improvement in product convenience and quality.

In addition to the foregoing system design changes that have been incorporated in pool cover equipment now being marketed, several minor improvements have been made.

(1) Control relays have been replaced with a type which can be manually actuated (by means of a push-button on top of the relay case), thereby enabling the system installer or maintenance worker to test the operation of the relay and the entire system from the location of the motor box. Eliminated is the former inconvenience of the worker having to move back and forth between the elevated motor box and the control station at pool-side.

(2) Brackets or hangers for mounting motor box and idler frame on the natatorium wall have replaced direct fastening of the back of boxes to the wall. Structural 3 x 3 -inch aluminum angles are bolted to the wall, and the sides of the motor box and idler frame are bolted to the angles. Installation ease and accuracy are thereby improved.

B. System Designs and Tests at Boys and Girls Club Pool

Listed in Section A are several system design improvements that were implemented and tested at the Denver Boys and Girls Club swimming pool. The most important of these developments are:

(1) Comparative testing of fabrics in full-size covers on pool, (See this report, Section A-1)

(2) Testing of methods for joining fabric pieces into full-size cover, (A-1)

- (3) Testing of improved pockets and sleeves for reinforcing cover, (A-1)
- (4) Testing of transparent plastic sheet connecting cover to reel, (A-1)
- (5) Testing of improvements in materials and design of cover edges and thickening materials near edges and at center of cover, particularly with respect to influence on regularity and smoothness of cover roll on reel, (A-1)
- (6) Testing of resistance of improved cover stays to forces tending to penetrate ends of retaining sleeves, (A-1)
- (7) Testing of material and method for achieving improved flotation of tow-bar, (A-1)
- (8) Testing of lengthened (24-foot) reel and widened (22-1/2-foot) cover, (A-2)
- (9) Testing of regularity and smoothness of cover roll on reel in system not provided with separate guide spindle, (A-2)
- (10) Testing of improved braking system for tensioning tow-rope, (A-2)
- (11) Comparative testing of 24-volt control system containing momentary rocker switch, with photocell shut-off, with stop-bar micro-switch shut-off, and with no automatic shut-off, (A-2)
- (12) Testing of roller chain tensioning cam for improved pillow-block positioning, (A-2).

C. Demonstration and Performance Tests at Skyland Recreation Center, Denver, Colorado

Task 4 of this project has been the selection of a demonstration site, manufacture and installation of a pool cover system incorporating the improvements developed in this project, the detailed measurement of energy use and savings realized by use of pool covers, and the dissemination of performance results. This task has been fully implemented at the pool of the Skyland Recreation Center in Denver.

1. Site Selection

The principal factors dictating the choice of a site for demonstration, testing, and evaluation of the improved pool cover system have been:

- (1) Interest of pool owner in saving energy
- (2) Size and shape of pool and a natatorium amenable to pool cover installation
- (3) Pool operating conditions favorable to large energy savings - air and water temperature, air humidity, and pool use schedule
- (4) Water heating and air heating equipment with fuel metering capability, adequate ventilation design, humidity control capability, and absence of obstructions to movement of cover
- (5) Capability for accurate monitoring of system performance

(6) Public visibility of facility with respect to dissemination of operating results and savings achieved.

In consideration of all the foregoing factors, the Skyland Recreation Center of the Parks and Recreation Department of the City of Denver was selected for demonstration, monitoring, and evaluating of the improved pool cover system.

2. System Design, Fabrication, and Installation

As shown in Figures 4 and 5, two motorized pool cover systems and two manual covers were installed at the Skyland pool. Manual covers were used in the small diving area of the L-shaped pool for practical reasons. The motorized units employ 24-foot reels. The covers are 22-1/2 feet wide and cover the entire 25-meter length of the large swimming area. All of the design improvements described in the foregoing sections of this report were incorporated. The principal new features are the lengthened reel, wide cover, 24-volt control system, improved rope-tensioning (rope-spool brake) of two types, single reel without guide spindle, automatic shut-off by photocell and by stop-bar switches, and improved cover material and design. One unit contains a spring-tensioned brake band on the rope spool sheave, and the other a V-belt segment on a hinged arm. Photocell shut-off is used in one motorized unit, and stop-bars acting against limit switches are used in the other. These design alternatives will be evaluated by comparing their performance over an extended time period.

3. System Testing and Evaluation

Following initial trials and adjustments, the pool covers were put into regular service in the Spring, 1995. Shortly thereafter, Mr. C.C. Smith, energy consultant on this project, installed monitoring equipment for determining energy consumption with and without pool cover use. Natural gas supply to the pool water heater and to the ventilation air heater was measured by use of special meters provided and installed by the Public Service Co. of Colorado. During eleven periods of 12 to 42 hours duration when the pool was not in use, water temperature, indoor air temperature and humidity, outdoor air conditions, and gas use in water and air heaters were measured and recorded. In six tests, the pool was not covered, and in five tests, all covers were on the water surface. Automatic control of pool temperature (by thermostat) and of natatorium humidity (by humidistat installed for these tests) was maintained.

Deployment of No. 1 cover onto Skyland pool during L.E.S.I./D.O.E.. presentation meeting on April 21, 1995.

Figure 4

Plan View of Skyland Swimming Pool

Figure 5

The Smith report of the project at the Skyland pool is included in this Final Report as Annex B. Extracted from that report is the following Executive Summary:

Executive Summary

A US Department of Energy grant was provided to Lof Energy Systems to develop and demonstrate current technical innovations pertaining to the operation of automated swimming pool covers. Since the purpose of pool covers is to provide energy savings by reducing pool surface evaporation, an essential element of the demonstration was to provide measurements and meter readings which quantify and verify the true savings.

Energy savings were observed in three processes which are needed to maintain comfort conditions in a swimming pool facility: heat supply to the pool using a hot water boiler, heat supply to ventilation air heating, and electrical power to fans for ventilation air supply. There is a fundamental and generally recognized savings in these energy applications associated with reducing evaporation. Proof of the magnitudes of such savings under normal pool conditions is essential, however, to provide the confidence needed by financial decision makers regarding pool cover investment. Other benefits of pool covering can also be considered, although of lesser importance than energy savings. These include water, sewer, and water treatment chemical cost savings. Pool safety can also be increased by covering, since a pool is clearly shown to be closed to swimming when a cover is in place.

The Skyland Recreation Center pool cover demonstration showed a 73% reduction in natural gas usage while covers were in place. For the particular case of this pool, with approximately 5000 hours of closed time per year and natural gas costing \$0.29 per hundred cubic feet, the annual cost savings are \$12,700. At a \$35,000 (Lof Energy Systems quotation) installation cost for covering the 4,700 square foot Skyland pool, the investment has a simple payback period of between two and three years.

Also reproduced from Smith's Skyland report is Figure 6 showing average gas use and savings for water and air heating based on the eleven controlled tests in March and April.

Figure 6 Gas Use and Savings in Tests at Skyland Pool

By use of results obtained in the eleven tests and statistics on average monthly atmospheric temperatures and humidities in Denver, the monthly and annual use and cost of fuel for the Skyland pool during regularly covered periods and for the same periods if not covered was computed and tabulated. Figures 7 and 8 from Smith's Skyland report show the computed annual gas use, costs, and savings.

Figure 7 Computed Annual Gas Use and Savings at Skyland Pool

Figure 8 Computed Annual Costs and Savings at Skyland Pool

The computed annual saving of \$12,700 is based on a low gas price of \$0.29 per CCF and 5000 hours of pool cover use per year. At a more typical U. S. natural gas price of \$0.50 per CCF, annual savings would be \$20,500, resulting in a pay-back period of about one year and nine months.

4. Dissemination of Test Results

Also resulting from the demonstration and testing of the pool cover system were a presentation meeting at Skyland and two published articles. At the presentation of the pool cover system to the City of Denver, city officials, swimming pool builders, representatives of DOE, the State of Colorado, an engineering society, and the public utility company observed a demonstration of pool cover operations and received information on the testing program and on the energy savings achieved. Preliminary results of energy use and projected savings were presented by C. C. Smith.

Publications containing information on the project and its results are:

"Swimming Pools Warm Up to Energy-Saving Technologies", an article in a DOE publication, Tomorrow's Energy Today for Cities and Counties, Sept., 1995.

"RSPEC! Pool Cover Partnership", an article in the ICP Observer, Issue 11, Summer, 1995, a publication of the DOE Institutional Conservation Program.

Copies of these two publications are included in this report as Annex C and D.

D. System Certification by Underwriters Laboratory

Task 3 of this project is the preparation for, and procurement of, UL certification of one or more models of the pool cover system. The original project plan included completion of UL certification within the active period of the grant, but several factors forced delay of completion. The principal reason for deferrment was the decision to complete Task 4 - demonstration and evaluation of prototype system - before submitting designs and test equipment to Underwriters Laboratory for certification as required in Task 3. This decision provided greater assurance that the first system submitted to UL would qualify for certification and that corrective requirements would be minimized. An additional benefit of reversing the order of Tasks 3 and 4 is UL's decision, described below, to do part of their testing on the operating system installed at the Skyland center as part of Task 4.

After completing the demonstration and evaluation of the improved system in Spring and Summer, 1995, the UL certification effort was initiated. Several procedures for conducting this effort were investigated, including direct correspondence and conversation with the head office of the Underwriters Laboratories in Northbrook, Illinois. In conformity with UL procedures, further action was transferred to its Santa Clara, CA facility.

By means of a detailed letter, Mr. Chris Hutchings, Engineering Group Leader at the Santa Clara office was provided the specifications of all components and materials in four models of the system: semi-automatic, hand-guided, radio-controlled Models 14 and 24, and fully automatic motorized Models 15 and 25. He was also provided information on the full-scale Model 25 units in operation at the Skyland Recreation Center.

On the basis of the above information, it was decided that the certification procedure would require submitting to the Santa Clara laboratory a complete motor and control assembly in a Model 24 (radio-controlled) unit, for testing and evaluation at that facility. The reel and cover will not be necessary for those tests. In addition to laboratory evaluation of the Model 24 prototype, inspection and testing of one of the Model 25 complete systems will be performed at the Skyland center by a UL technical representative. The results of laboratory evaluation of the Model 24 motor/control assembly and field evaluation of the complete Model 25 system will be the basis for UL certification action.

As explained in previous progress reports, the costs of conducting and completing Tasks 1, 2, and 4 exceeded estimates in the original budget. It has therefore been necessary to use grantee's own funds for the full cost of UL testing and certification.

Grantee is fully committed to taking all actions necessary for procuring UL certification of at least one model of the pool cover system. It is expected that such a rating will be obtained early in 1996.

E. Preparation of Manuals

The final phase of Task 2 is the preparation of manuals for assembly, installation, operation, and maintenance of motorized swimming pool cover systems developed in this project. These materials are designed for use by personnel with practical training and experience with mechanical and electrical equipment. Two documents have been prepared - "Motor Box Assembly Procedure" and "Operations and Maintenance Manual".

The assembly procedure manual is a 17-page set of step-by-step instructions, with diagrammatic sketches, for constructing a

fully operational Model 15 or 25 motorized system. It is accompanied by a set of Production Drawings for Model 15 comprising 13 scale drawings, with dimensions, of motor box components and sub-assemblies, two drawings of photocell supports, and four drawings of end-brackets, reels, and hubs. A comparable set of Production Drawings for Model 25 is also part of the Motor Box Assembly Procedure manual. This document is used only by shop personnel who manufacture and assemble systems in company facilities. Certain drawings, such as motor-box enclosures, are also provided to sub-contractors as specifications for components fabricated by them for company purchase and use.

The Operations and Maintenance Manual is a copyrighted 44-page document provided to all owners of pool cover systems supplied by the company. It is also available to all persons who install, maintain, and repair these systems. It contains general information, directions and cautions for using covers, detailed instructions for operating controls that cover and uncover the pool, information on electric motor, speed reducer, torque limiters and drive chain, and controller. Also included are directions for trouble-shooting and correcting minor operating problems, electric wiring diagrams, information on photoelectric components, and technical data on reels and supports.

There is no separate manual for installing systems, but the Operations and Maintenance Manual has adequately served experienced installers. To acquaint inexperienced personnel with installation procedures, the "apprentice" relationship has been successfully used, the new employee working under the direction of an experienced installer. As company operations expand, however, a detailed installation manual will be prepared and made available to all installers of these systems.

III. MANAGEMENT SUMMARY

A six-month extension of the grant to a final date of September 30, 1995, made possible the completion of all proposed Tasks except Underwriters Laboratory certification of the pool cover system, which, however, has been initiated and will be completed.

The final performance schedule is presented in this report.

Task 1, pertaining to cover materials, cover fabrication, and testing has been completed. Woven polyolefin (polyethylene or polypropylene) has been selected as the best material for indoor pool covers, and foam-laminated material has been chosen for sewn-on strips for flotation and improved alignment on reels.

Task 2 is also complete. The lengthened reel, widened cover, and improved motor box and controller have been fabricated and tested. Two types of automatic motor-stop equipment have been adopted, and two new braking (rope-tensioning) systems have been successfully tested. Final selections will be based on extended experience with the operation of these systems. A finalized shop assembly manual and an operating and maintenance manual have been prepared and placed in service.

Task 3, UL approval of system is in progress as the grant project is completed September 30, 1995. Approval, by a licensed electrical engineer, of both control systems used in the Skyland pool demonstration installation has been obtained, thereby supporting the UL certification application. Agreement has been received from UL to receive and test system models and, subject to successful testing and satisfactory results, to provide UL certification. This effort will be pursued, at company expense, to completion, expected early in 1996.

In Task 4, design and demonstration of improved pool covers, monitoring and reporting of savings, and dissemination of results have been completed. A detailed report of results is included in this final report to DOE.

The first dissemination of results took place at the presentation meeting April 21, 1995. Subsequent disclosures and publications were made, and detailed performance results are included in this Final Report (Task 5), of September 30, 1995, the termination date of the project.

IV. FINANCIAL SUMMARY

Total project expenditures to March 31, 1995, were \$92,119, of which \$77,219 was the federal share and \$14,900 was the grantee share (16%). Combined DOE and grantee expenses in the April-September, 1995 period have been approximately \$31,000, bringing the costs of the project through September, 1995, to a total of \$123,119. This total exceeds the \$99,453 approved budget for the grant, of which the federal share is \$83,310 and the grantee share is \$16,143. The entire approved federal share of \$83,310 has been received by the grantee. Total project expenditures of \$123,119 minus \$83,310 received from DOE equals \$39,809 provided by grantee, 32.3 % of the total.

A request was made on February 20, 1995, to Elliott Levine of the DOE-ERIP program office, for additional DOE support of the work in the final six months of the project, primarily for pursuit of UL certification of the system and for the preparation and dissemination of reports, manuals, construction bulletins, and technical papers. No additional funds have been provided, however, but grantee hereby renews the request for financial assistance in meeting costs of UL certification and in additional dissemination of useful information on the benefits of pool cover systems.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

86-010

AUTOMATIC STORAGE REEL

AUTOMATIC POOL COVER REEL SYSTEM

Motorized covers can save \$7,000 to \$10,000 in energy costs each year on a 45' x 75' indoor pool. Energy losses are stopped by placing the patented Löff motorized pool cover onto the water surface when the pool is not in use. The mono-layered pool cover is an evaporation barrier that virtually eliminates the need for expensive water heating and air drying when the pool is closed.

Evaporation consumes much of the energy lost from indoor pools. Without an evaporation barrier or replacement heat, the temperature of the pool water will drop. Water evaporated into the indoor air must be removed by mechanical systems. If moisture is not removed from the indoor air, the high humidity will damage the building and its fixtures, as well as violate comfort and health standards. This energy problem is recognized in ASHRAE Standard 90.1-1989 which requires covers on heated pools. Regularly covered pools also use less water treatment chemicals and less make-up water.

These motorized covers are easy to operate, encouraging daily use. The operator starts and stops the pool cover by simply pressing a button. The standard lockable, wall-mounted control box enables one person to cover or uncover a public pool in about three minutes. When the control box is locked the controls are inaccessible.

The pool covering systems can be used on almost any indoor pool. Most covers are applied to pools 10 to 30 meters wide and 25 to 50 meters long. Each reel unit covers a 15 to 22 foot wide section of water. Multiple mountings of the units provide coverage of even the largest public pools.

The Löff system operates without tracks or other deck modifications. The wall-mounted motorized reels store the covers near the ceiling, allowing for full use of all deck space for swimming programs, activities, and maintenance chores. Optional stand-off mountings

are available for unusual walls. Unique custom-engineered ceiling mounting hardware allows the pool covering systems to be suspended from ceilings.

86-005 Löff model 24 hand-guided motorized cover system

86-010 Löff model 25 automatic cover system

WALL-MOUNTED REELS

WALL MOUNTED STORAGE REELS — Constructed of .120" wall stainless steel. Each unit mounts directly onto facility walls and can be staggered to handle pool cover panels straight off the pool. Conserves deck space and makes covers easy to handle. Each reel includes: 2 stainless end support frames, 1 stainless winding tube, 2 pillow block bearings, 3 pool cover attaching straps, and 2 stainless hand wheels. Mounting hardware not included. Maximum capacity of each reel is 150 lineal feet or 2,000 lbs. of pool cover material. Each unit mounts with four, 4" x 4 1/2" x 1/4" stainless mounting plates drilled for 3/8" bolts. Reels should be approximately 1' wider than the width of the pool cover panel it will be holding. Ten year warranty.

86-015 10'

86-020 11'

86-025 12'

86-030 13'

86-035 14'

86-040 15'

86-045 16'

86-050 17'

86-055 18'

86-060 19'

86-065 20'

86-110

PORTABLE REELS

SOLAR COVER REELS — Commercial grade reel system for use with solar covers. Made from anodized aluminum tubing. Heavy duty "T" base provides maximum strength and stability. Locking casters turn 360° for easy portability. **2 year warranty.**

Reel Size	Blanket Width	Single Reel	Double Reel
16'	14'	86-070	86-100
18'	16'	86-075	86-105
20'	18'	86-080	86-110
22'	20'	86-085	86-115
24'	22'	86-090	86-120
26'	24'	86-095	86-125

SOLAR COVER REEL PARTS — Replacement parts for the solar commercial reel system.

86-130 Replacement hand wheel

86-135 Replacement end cap, black

86-140 Replacement nylon yoke

86-145 Replacement 5" locking caster

86-150 Replacement caster acorn nut

86-155

ODYSSEY PORTABLE REELS — Unique triangular base design allows you to roll reel to pool-side and then secure the reel by tipping it back on the non-movable portion of the base. High-impact PVC construction with adjustable aluminum reel tube and 4" casters. Will accommodate up to 26' wide x 70' long bubble cover panel. Optional Power Pack attaches to your garden hose and allows you to automatically remove and replace your pool cover.

86-155 Odyssey portable reel

86-160 Odyssey power pack

**City of Denver
Skyland Recreation Center**

POOL COVER ENERGY SAVINGS ANALYSIS

prepared for

Lof Energy Systems, City of Denver, and the US Department of Energy

by

Charles C. Smith, P.E.

September 14, 1995

ANNEX B

Executive Summary

A US Department of Energy grant was provided to Lof Energy Systems to develop and demonstrate current technical innovations pertaining to the operation of automated swimming pool covers. Since the purpose of pool covers is to provide energy savings by reducing pool surface evaporation, an essential element of the demonstration was to provide measurements and meter readings which quantify and verify the true savings.

Energy savings were observed in three processes which are needed to maintain comfort conditions in a swimming pool facility: heat supply to the pool using a hot water boiler, heat supply to ventilation air heating, and electrical power to fans for ventilation air supply. There is a fundamental and generally recognized savings in these energy applications associated with reducing evaporation. Proof of the magnitudes of such savings under normal pool conditions is essential, however, to provide the confidence needed by financial decision makers regarding pool cover investment. Other benefits of pool covering can also be considered, although of lesser importance than energy savings. These include water, sewer, and water treatment chemical cost savings. Pool safety can also be increased by covering, since a pool is clearly shown to be closed to swimming when a cover is in place.

The Skyland Recreation Center pool cover demonstration showed a 73% reduction in natural gas usage while covers were in place. For the particular case of this pool, with approximately 5000 hours of closed time per year and natural gas costing \$0.29 per hundred cubic feet, the annual cost savings are \$12,700. At a \$35,000 (Lof Energy Systems quotation) installation cost for covering the 4,700 square foot Skyland pool, the investment has a simple payback period of between two and three years.

Purpose of Pool Cover Energy Analysis

An energy savings analysis was conducted as a major component of a US Department of Energy "Inventors Grant" aimed at the development and demonstration of automated pool covering technology. Covers are deployed whenever a pool is closed to swimmers as a method of saving energy by reduced evaporation. Some evaporation energy loss occurs even with the cover in place due to uncovered areas around the cover perimeters or to any water on top of the cover.

Energy savings can be realized both in pool heating and in the ventilation air supply for an indoor facility by use of pool covers. Less outdoor air is needed to maintain a set humidity inside a natatorium when the evaporation rate is reduced. This means less fresh air heating in cold seasons, and less fan power even if there is no heating required.

Pool water heating has been measured under previous testing projects, however actual meter readings of fuel or electric usage resulting from covers has not been closely observed. Also ventilation air energy reductions have not been measured previously which result from lower evaporation rate.

Pool Energy Testing Site Conditions

A city of Denver Recreation Department (Skyland Recreation Center) pool was selected from among three candidates for the pool cover energy analysis. The site is at high elevation with a climate exhibiting widely ranging temperatures and low atmospheric humidity.

The pool is 4730 square feet area, "L" shaped, with swim lanes and a dive well(Figure 1). The natatorium is spacious with high ceilings and clerestory style windows. The dimensions of the pool and natatorium room are presented in Appendix A. The total wetted area, which includes perimeter gutters, is 5030 square feet.

The pool is multi-use although athletic swimming and diving were absent from the programs. Water temperatures are maintained unusually warm (84-88 degrees F) to suit the preferences for aquatic exercise programs and play periods.

Figure 1-View of 4730 square foot Skyland Swimming Pool

Air conditions over the pool were a primary consideration in the energy study and the subject of some recommended changes which were implemented during the course of the testing program. Existing rooftop heating and ventilating equipment was adequate to provide temperature and humidity control in the pool enclosure. A unitized heating/ventilating unit consisted of modulating gas burners, a 10 kw belt driven fan, air filters, and indoor/outdoor control dampers. A schematic diagram of this unit is presented in Figure 2. In addition to this packaged heating/ventilation unit, two exhaust air fans (a 1kw and a 1.8kw) were installed on the roof. These were axial flow units with dampers which opened by fan air force. Figure 3 shows the roof mounted heating/ventilation and exhaust units.

Initially the humidity was not under automatic control and air was entering via an open passage between the natatorium and other areas of the building; a gymnasium, entry corridor, and fitness area. This condition was providing acceptable comfort levels in the facility however there was no monitoring ability on air supply energy due to unknown sources of the air entering the pool area. Also this resulted in very low natatorium humidity levels at times, and particularly when the pool cover was in place.

— The pool heater was a 726,000 Btuh Raypak natural gas fired boiler which was newly installed only nine months prior to testing. Temperature control on the return line of water from the pool to the boiler was capable of maintaining the pool within about 2-3 degrees F of the setting. The unit has a name plate efficiency of 76%. Seventy percent was used for the energy calculations however, allowing for some standby losses.

Figure 2-Diagram of rooftop heating/ventilating unit.

Figure 3-View of heating/ventilating(center) and exhaust air(far right)units.

Monitoring Equipment

In order that pool evaporation rate could be reliably correlated with the conditions in the pool, it was necessary to maintain close observation of pool water temperature, air temperature, and air humidity. Air and water conditions were monitored and used to calculate the ASHRAE evaporation rate at six-minute intervals using a desk top computer(Figure 4). Pool water, and air temperatures were measured with T-type thermocouple junctions. Outdoor air temperature was also monitored for use in ventilation air energy measurements.

Air humidity measurement was obtaining by monitoring the dew point temperature with an EG&G Model 660 dew point hygrometer (Figure 5). This instrument was calibrated prior to testing to ± 0.2 degrees C against a secondary dew point temperature standard. This calibration translates to approximately ± 0.6 percent relative humidity.

Figure 4- View of data acquisition unit(right), and computer(left) used to process the pool measurements.

Figure 5- View of dew point hygrometer used to monitor air humidity over the pool.

New gas meters were installed by Public Service Company of Colorado for the purpose of these tests. Gas meter error was not known. However since the same meters were used for cover off and on testing, such errors should be consistent for both cases. Meters were located on gas lines entering directly into both the pool water heater and the air heater(rooftop unit described above).

Pool Cover Installation and Operation

A Lof Energy Systems pool cover was installed at the facility during February of 1995, just prior to energy testing(Figure 6). Two covers which extend along the full length of the swim section are automated. These covers are activated at a wall mounted control panel on the long wall nearest these covers.Two covers over the diving section of the pool are manually operated (Figure 7).

Appendix A provides a plan view with dimensions showing the coverage area when the covers are deployed on the water surface. When the covers are placed down fully to the gutters, both on the reel and tow ends, they provide 4424 square feet of coverage. This represents 88 percent of the 5030 square foot wet area(pool surface plus gutter area).

Two factors at Skyland contributed to additional water surface exposure. A handicapped stair and rail unit was installed just after the covers which holds the cover off the water in one corner of the pool. This was estimated to be one hundred square feet. Also adding to evaporation was occasional water on top of the cover. This can occur during the covering process if the leading edge of the cover(towbar) dips below the water surface. The hollow towbar tubing provides

Figure 7-View of manually deployed covers on the pool at Skyland

Figure 6-View of motor driven covers placed on the pool at Skyland

flotation along the front edge, however if the bar approaches the water surface from a high angle or if it is drawn at too high a speed, water can wash onto the cover. Such wetting over the cover is highly variable and was observed to range from zero to approximately 10 percent of the total cover area.

Pool Water Heating

The major cost of pool operation at Skyland, as with any heated pool facility, is in providing the energy to maintain the pool at a comfortable temperature. Left unheated, a pool would cool to approximately the wet bulb temperature of the air above which is several degrees below the comfort level. Energy must be supplied continuously to the pool at a rate equal to heat losses. The losses are due to various causes but mostly due to the evaporation occurring from the pool surface into the air above. The evaporation rate, and hence the energy loss rate due to evaporation, is governed by the equation:

$$PHc = (71.4 + .38*v)*(P_w - P_a) \quad (a)$$

Where: PHc- modified ASHRAE evaporation energy rate, btu/hr-sq ft
v- air velocity over water surface, ft/min
 P_w -saturation vapor pressure at the water temperature, in. Hg
 P_a -saturation vapor pressure at the air dewpoint, in. Hg

Typical evaporation of a pool at 80 degrees F, with air temperature of 80 degrees F and humidity of 50 percent, is at a rate of approximately 0.25 inch per day or 1.3 pounds per square foot per day. Since evaporation cools the pool water at a rate of 1040 btu per pound (the latent heat-Y), the pool heater must supply approximately 55 btu per hour per square foot of pool surface.

Evaporation rate is increased by activity and air movement(v in the above equation), however these factors do not enter in to an analysis of pool cover energy savings.

Pool water heating at the Skyland facility was provided by typical means. Pool water which overflows into the perimeter gutters flows into a surge tank. From there it is pumped continuously through a sand filter and the pool heating boiler before returning to the pool. Pool water heating is regulated by on/off control of gas burners in response to a thermostat in the water line entering the boiler.

Ventilation air Heating

It is generally recognized that pool water heating is directly reduced by the use of pool covering. It is less clear how effective covering a pool can be in reducing ventilation air heating to the pool enclosure. As water evaporates from the pool surface it must be removed from the room by supplying lower humidity air, either from outdoors or a dehumidifier unit. Most modern pool facilities have humidity control which automatically operate dampers and fans for ventilation to maintain a humidity setting, for example at 50 percent.

The theoretical minimum amount of ventilation air required to remove the evaporated water is easily calculated by the formula:

$$AMF = EW / (X_{in} - X_{out}) \quad (b)$$

where: AMF-The minimum air flow rate necessary to maintain a fixed humidity level in the building, lb/hr
EW-The rate of water evaporation from the pool into the air, lb/hr
X_{in}- The humidity ratio of the room air, lb_{water}/lb_{dry air}
(from psychrometric chart or formula)
X_{out}- The humidity ratio of the outdoor air, lb_{water}/lb_{dry air}
(from psychrometric chart or formula)

If the room air temperature and humidity are closely controlled, two factors influence the ventilation air volume requirement; pool evaporation rate and the outdoor(or dehumidifier supply) air humidity ratio. The heating requirement to raise the ventilation air quantity from the outdoor to indoor temperature can also be calculated directly as:

$$VH = 0.24 * AMF (RAT - OAT) \quad (c)$$

where: VH-The minimum air heating for ventilation air, btu/hr
0.24-Specific heat of air at typical conditions, btu/lb-degree F
RAT-Average room air temperature, degree F
OAT-Average outdoor air temperature, degree F

Thus for any given set of temperature and humidity conditions of indoor and outdoor air, the energy savings for ventilation air should be proportional to the reduction in pool evaporation rate. This however had not been verified by closely observed energy measurements in the past.

A necessary condition for true measurement is isolation of the ventilation air and heating from other sections in the building and also of the energy (fuel or electric) supply. If the ventilation air conditions can be correctly managed and measured, the proportionality of energy savings by pool covering during a few test periods can be projected to the annual energy calculated for this application. This was accomplished in the Skyland pool testing program.

Humidity Control

An important consideration in this project was to leave conditions as they were found to be in practice at the facility in order to present a true example of energy savings occurring due only to pool covering. The only departure from this theme was regarding the ventilation air conditions. An open, four by seven foot passage between the natatorium and the other building areas was closed off during testing hours, and automatic humidity control was implemented.

With the passage closed, the natatorium temperature and humidity conditions were entirely provided by three rooftop heating/ventilating units; a supply air unit with fan, natural gas heater, fresh air damper, and filters, and two separate exhaust air fans. Initially the exhaust air fans were manually controlled; normally left continually on. The fresh air damper was left in the closed position at all times such that ventilation air was supplied via the open passage or from infiltration openings. A strong negative air pressure existed when one or both exhaust air fans were operating and the fresh air damper was closed. Room air temperature was maintained by a modulating gas burner.

Early tests revealed that humidity varied widely under these conditions and dropped to as low as 20 percent relative humidity with the cover in place. Thus humidity control was installed. A control sequence was initiated by a wall mounted humidistat circuit closure upon high humidity (i.e, above 50 percent). The fresh air damper was powered to open. At full open position, the supply air fan and one of the two exhaust air fans came on. The second exhaust air fan remained as a manually controlled unit. As the fresh air requirement was met and humidity level fell below the setpoint, this sequence was reversed.

Measurements and Data Collection

Measurements of pool water temperature, air temperature, and air humidity were made during closed periods of approximately twelve hours (from 7pm to 7am) on week days or during approximately forty two hours on weekends. This

was necessary even though these parameters were under automatic control because control was not precise enough for the energy calculations. Pool water temperatures were found to range between 82 and 92 degrees, air temperature between 78 and 84 degrees, and air humidity between 40 and 60 percent.

To allow for these variations it was necessary to divide the testing period into small time steps and the evaporation amount calculated for each of the small time periods. Measurements at six minute intervals(one-tenth hour) were made and the evaporation quantity calculated using equation 1. Total evaporation was thus predicted by addition of the six minute values over the test period.

Natural gas cubic feet readings were taken at the beginning and end of each test period using newly installed gas meters on the pool boiler and rooftop air heater. Also the outdoor wet and dry bulb temperatures were observed at the beginning and end of tests. An extension of the testing program was conducted to make observation of exhaust and supply air fan running times. These times were used, together with the power ratings of the fan motors, to also measure electrical energy savings resulting from covering the pool.

Precision initial and final measurements of pool water temperature were necessary in addition to the boiler gas input in determining the evaporation energy consumption. Energy released from a one degree change in the pool temperature was equivalent to energy lost in approximately two hours of open pool or six to eight hours of covered pool. Temperature measurements were made of pool water to an accuracy of 0.1 degree F, or to a 0.2 degree F temperature difference allowing for a 0.1 degree F error in opposite directions at the start and end of a test period. Thus for a twelve hour test period, open water tests could be in error by as much as four percent and covered pool by as much as ten percent due to pool temperature change.

Calculation Procedure

As discussed previously, temperature change of the pool water needs to be considered in addition to the gas boiler input. The amount of gas used to meet heat losses is therefore the meter consumption (cubic feet) during a test period adjusted to what it would be if there were no water temperature difference between the start and end of a test. The formula used for this adjustment includes the mass of water, the boiler efficiency factor, and the natural gas heating value(btu/cu ft). For example, if the Skyland pool temperature rises one degree F during a test period, 1.6 million btu are simply added to the pool

water and are not consumed or lost. Considering the boiler efficiency factor and natural gas heating value, 27 ccf of gas are subtracted from the meter reading in order to represent the quantity of gas that would have been used if the pool temperature had remained constant. It is that adjustment quantity that is proportional to actual pool water evaporation. Correspondingly, for a pool temperature decrease during a test, the appropriate gas quantity is added to the meter reading.

Tables I lists and defines all of the parameters used in the Skyland pool energy study. It is divided into first the water heating parameters and secondly those pertaining to air heating. Equations for functions which are calculated are presented below the definition statements. Function labels which end with "c" are calculated by the same method used in the RSPEC program.

Table I
Definition of Column Headers-Skyland Pool Data Sheets

Pool Water Heating (Found in Table III)

- No- The sequential test number
- Date- Date of starting test
- hrs- Test duration to 0.1 hours
- PT- Average Pool water temperature, degrees F
- RAT- Average room air temperature, degrees F
- PRH- Average pool air relative humidity, %
- PG- Gas meter reading at end of test minus reading at start of test,
cubic feet
- PHG-Rate of energy delivered to pool from the boiler during the test
period, btu/hr

$$PHG = PG * \text{Gas Heating Value}(840 \text{ btu/cf}) * \text{Boiler Efficiency Factor}(0.7) / \text{hrs}$$
- PHin- Rate of energy input to the pool, btu/hr-sq ft

$$PHin = PHG / \text{Pool Area}(4730 \text{ sq ft})$$
- TPs- Pool water temperature at the start of test period, degrees F
- PTf- Pool water temperature at the finish of test period, degrees F
- PHdif-Energy difference from pool temperature change during the test
period, btu/hr-sq ft

$$PHdif = \text{Water Mass}(1,605,000 \text{ lb}) * (PTs - PTf) / [\text{Pool Area}(4730 \text{ sq ft}) * \text{hrs}]$$
- PH- Total heat to pool without temperature change, btu/hr-sq ft

$$PH = PHin - PHdif$$

PGE- Gas equivalent to pool heating without temperature change,
cubic feet/hr

$$PGE=4730*PH/(840*0.7)$$

PHc- The calculated sum of six minute evaporation energy using
equation (a), btu/hr-sq ft

Air Heating (Found in Table IV)

No- The sequential test number

Date-Date of starting test

hrs- Test duration to 0.1 hours

PT- Average Pool water temperature, degrees F

RAT-Average room air temperature, degrees F

PRH-Average pool room air relative humidity, %

OAT-Average outdoor air temperature, degrees F

ORH-Average outdoor air relative humidity, %

VG- Gas meter reading at end of test minus reading at start of test,
cubic feet

VHG-Energy delivered to air heating during the test period, btu/hr

$$VH=VG*Gas\ Heating\ Value(840\ btu/cf)*Air\ Heater\ Efficiency\ Factor(0.7)/hrs$$

VH- Rate of energy input to air, VHG/Pool Area(4730 sq ft),
btu/hr-sq ft

Tdif- RAT-OAT, degrees F

EWc-The hourly pool evaporated water calculated from equation(1), lb/hr

$$EWc=4370*PHc/latent\ heat\ of\ water(1040\ btu/lb)$$

HDc-Humidity difference between indoor and outdoor air,
lb H₂O/lb Dry Air

(From psychrometric tables at 5000 ft elevation)

AMFc- Calculated minimum air mass flow needed to remove the
evaporated moisture, lb/hr

$$AMFc=EWc/HDc$$

VHc-The calculated energy requirement for ventilation air heating,
btu's/hr-sq ft

$$VHc=0.24*AMFc*(RAT-OAT)/4730$$

VGc- Calculated gas for ventilation air heating, cubic feet/hr

$$VGc=4730*VHc/(840*0.7)$$

Table II presents a sample calculation, in English units, corresponding to the parameters shown in Table I. The sample is taken from one of the pool test runs with the cover removed, test number 24 shown in Tables III and IV.

Table II
Sample Calculation Corresponding to Parameters in Table I
For a Test Run at Skyland

Pool Water Heating (Found in Table III)

No- 24
 Date- 4/11/95
 hrs- 12 hrs
 PT- 86 degrees F
 RAT- 81 degrees F
 PRH- 52 %
 PG- 5,820 cubic feet
 PHG- 285,180 btu/hr

$$\text{PHG} = \text{PG} * \text{Gas Heating Value}(840 \text{ btu/cf}) * \text{Boiler Efficiency Factor}(0.7) / \text{hrs}$$

 PHin- 60.3 btu/hr-sq ft $\text{PHin} = 285,180 / \text{Pool Area}(4730)$
 TPs- 85.8 degrees F
 TPf- 86.3 degrees F
 PHdif- (-13.3) btu/hr-sq ft

$$\text{PHdif} = \text{Water Mass}(1,605,000 \text{ lb}) * (85.8 - 86.3) / [\text{Pool Area}(4730 \text{ sq ft}) * 12 \text{ hrs}]$$

 PH- 47.0 btu/hr-sq ft

$$\text{PH} = 60.3 - 13.3$$

 PGE- 378 cubic feet/hr

$$\text{PGE} = 4730 * 47.0 / (840 * 0.7)$$

 PHc- 52.3 btu/hr-sq ft (see Appendix B for calculation method)

Air Heating (Found in Table IV)

No- 24
 Date- 4/11/95
 hrs- 12
 PT- 86 degrees F
 RAT- 81 degrees F
 PRH- 52 %
 OAT- 41 degrees F
 ORH- 55 %
 VG- 6408 cubic feet
 VHG- 313,992 btu/hr

$$\text{VHG} = \text{VG} * \text{Gas Heating Value}(840 \text{ btu/cf}) * \text{Air Heater Efficiency Factor}(0.7) / \text{hrs}$$

VH- 66.4 btu/hr-sq ft $VH = 313,992 / \text{Pool Area}(4730)$
 Tdif- 81-41=40 degrees F
 EWc-238 lb/hr
 $EWc = 4370 * 52.3 / \text{latent heat of water}(1040 \text{ btu/lb})$
 HDc-0.0111 lb H₂O/lb Dry Air
 (From psyrometric tables at 5000 ft elevation)
 AMFc- 21,359 lb/hr
 $AMFc = 238 / 0.0111$
 VHc- 43.4 btu's/hr-sq ft
 $VHc = 0.24 * 21,359 * 40 / 4730$
 VGc- 349 cubic feet/hr
 $VGc = 4730 * 43.4 / (840 * 0.7)$

Water temperatures were consistently and significantly higher than the air temperatures at the Skyland pool during the tests. Such temperature difference can result in some convection heat transfer in addition to evaporation. For natural convection from a horizontal surface warmer than the air above:

$$H_{\text{conv}} = h * (T_{\text{pool}} - T_{\text{air}})$$

where:

H_{conv} -Convection heat loss rate, btu/hr-sq ft
 T_{pool} - Pool water temperature, degrees F
 T_{air} - Air temperature over pool, degrees F
 $h = 0.22 * (T_{\text{pool}} - T_{\text{air}})^{1/3}$

The temperature difference between air and water averaged six degrees when the pool was uncovered and eight degrees when covered; thus it is estimated at seven degrees over all. For a seven degree difference the convection heat loss (H_{conv}) is 3.1 btu/sq ft-hr.

Since the convection heat loss applies to both cases of cover on and off, it does not enter into the results of energy savings due to cover usage. However it does explain some of the energy loss that did occur when the cover was in place.

Results

Eleven tests were performed with a combination of good measurement and also good control conditions between March 28 and April 18 of 1995. Six of these tests are with no cover and five are with the cover in place.

The data values from these eleven test are presented in Tables III and IV. Both tables give the average temperatures and humidity during the test periods, the natural gas consumption, and energy consumption based upon measurement and also by calculation. Table III features the pool heating energy, and Table IV the ventilation air energy values. Numbers are given for each test and also the average of tests without the cover and of tests with the cover in use.

Headings of each column correspond to the definitions given in Table I. Terms with the ending letter "c" are derived from the RSPEC method of calculation, while all others are from observation or measurement. The tables present the measured values of energy used both in terms of heating units(btu's) and natural gas(cubic feet). The calculated numbers for the cover on assume an 85 percent surface coverage factor. Referring to the earlier cover discussion, this represents the exposed perimeter area plus some allowance for wetting on top of the cover.

The natural gas consumption is found in the tables labeled PGE for pool water heating and VG for air heating. As pointed out earlier, the pool heating gas figures are adjusted for pool temperature changes during the test period; the differences between PTs and PTf. PGE is derived as shown by the equation in Table I. The total pool heat values (PH) are divided by the gas heating value and the boiler efficiency factor for conversion to equivalent cubic feet of gas. Figure 7 is a bar chart presentation of the average energy measurements from Tables III and IV in terms of natural gas use(cubic feet per hour).

Figure 7-The average gas use measured in the Skyland pool tests

Table III

Skyland Swimming Pool

Water Heating Energy Summary-Cover OFF

No	Date	Hrs	PT	RAT	PRH	PG	PHG	PHin	TPs	TPf	PHdif	PH	PGE	PHc
18	3/28	12.0	89	81	47	6290	308210	65.2	89.1	89.4	-8.0	57.2	460	66.6
23	4/8	43	85	79	44	17145	234448	49.6	85.1	84.4	5.2	54.8	441	60.5
24	4/11	12	86	81	52	5820	285180	60.3	85.8	86.3	-13.3	47.0	378	52.3
25	4/12	12	85	77	51	5600	274400	58.0	85.0	85.0	0.0	58.0	467	58.0
26	4/15	42	87	78	55	16233	227262	48.0	87.1	86.5	4.6	52.6	423	45.0
28	4/18	12.5	86	78	46	812	38196	8.1	86.6	84.5	53.8	61.8	497	57.3
Average			86	79	49			48.2	86.5	86.0	7.0	55.2	444	56.6

Water Heating Energy Summary-Cover ON

No	Date	Hrs	PT	RAT	PRH	PG	PHG	PHin	TPs	TPf	PFdif	PH	PGE	PHc*
19	3/31	14.3	89	84	36	5900	3469	51.5	87.7	89.4	-38.2	13.3	107	11.1
20	4/1	40.8	88	81	34	2771	1629	8.5	87.6	88.4	-6.3	2.2	17	11.2
21	4/3	12.0	89	82	38	5978	3515	61.9	87.6	89.4	-48.0	13.9	112	10.9
22	4/4	12.0	89	80	44	5250	3087	54.4	88.2	90.0	-48.5	5.9	47	10.9
27	4/17	12.0	86	74	51	6342	3729	65.7	85.1	87.0	-50.7	15.0	121	8.0
Average			88	80	41			48.4	87.2	88.8	-38.3	10.1	81	10.4

* Calculated using 15% exposed water factor

Table IV

Skyland Swimming Pool

Ventilation Energy Summary-Cover OFF

No	Date	Hrs	PT	RAT	PRH	OAT	ORH	VG	VHG	VH	Tdif	EWc	HDc	AMFc	VHc	VGc
18	3/28	12.0	89	81	47	28	70	10632	520968	110.1	53	303	0.0119	25554	68.7	553
23	4/8	43	85	79	44	49	38	30100	411600	87.0	30	275	0.0084	32627	49.7	400
24	4/11	12	86	81	52	41	55	6408	313992	66.4	40	238	0.0111	21359	43.4	349
25	4/12	12	85	77	51	55	14	2544	124656	26.4	22	264	0.0107	24640	27.5	221
26	4/15	42	87	78	55	54	25	29064	406896	86.0	24	205	0.0104	19658	23.9	193
28	4/18	12.5	86	78	46	38	89	6238	293436	62.0	40	261	0.0083	31446	63.8	513
Average			86	79	49	44	49		345258	73.0	35	258	0.0101	25881	46.2	371

Ventilation Energy Summary-Cover ON

No	Date	Hrs	PT	RAT	PRH	OAT	ORH	VG	VHG	VH	Tdif	EWc*	HDc	AMFc	VHc	VGc
19	3/31	14.3	89	84	36	51	40	3532	145741	30.8	33	51	0.0074	6865	11.5	92
20	4/1	40.8	88	81	34	53	36	5467	78886	16.7	28	51	0.0060	8500	12.1	97
21	4/3	12.0	89	82	38	51	43	1836	89964	19.0	31	50	0.0066	7609	12.0	96
22	4/4	12.0	89	80	44	57	28	1284	62916	13.3	23	50	0.0089	5645	6.6	53
27	4/17	12.0	86	74	51	37	85	1596	78204	16.5	37	36	0.0080	4500	8.4	68
Average			88	80	41	50	46		91142	19	30	48	0.0074	6624	10.1	81

* Calculated using 15% exposed water factor

Direct comparison can be noted between measured and RSPEC calculated results from the tables. That is between PH and PHc, the water heating energy in Table III, and between VH and VHc, the air heating energy in Table IV. Taking the average values from Table III, the pool heating measurement was 55.2 btu/hr-sq ft, or 2.5% less than the RSPEC value of 56.6. With the cover on from Table III, the pool heating measurement was 10.1 btu/hr-sq ft, or 2.9% less than the RSPEC value of 10.4.

From Table IV, it is seen that the RSPEC value(46.2 btu/hr-sq ft) for air heating was 37 percent below the measured(73.0 btu/hr-sq ft) without pool covering. Using the cover, an RSPEC calculated value of 10.1 btu/hr-sq ft is 47 percent below a measured average value of 19.0. There is a sizable transmission heat loss through walls and windows which accounts for some heating in addition to the ventilation heating alone. Also there are infiltration openings to the outside, mostly under and around doors which add to the heating load in spite of efforts to isolate the natatorium air to the ventilation system.

The indoor "RH%" column of Table IV shows that humidity was lower on some of the covered tests even though the humidistat was set at 50% for both the covered and uncovered periods. This is explained by two causes; the main circulation fan created a high negative pressure at the fresh air control damper which was not tight sealing and could introduce excess air when the evaporation rate was sharply reduced. Secondly, similar to the pool overheating explanation, the equipment is oversized for the covered condition and can remove too much of the room air before the controls can respond to reduce ventilation.

Table III shows a trend of pool temperature rise with the cover in place and a fall with the cover off. This condition was noted by life guards and others at Skyland, leading to an opinion that the cover itself heats the water. Under exact boiler thermostat control the pool temperature would be held constant at the desired setting regardless of the covering status. Pool overheating while the cover is in place can occur because the boiler capacity is large compared to the greatly reduced heating load.

Electrical Power Savings

Electrical power for lighting and pool water circulation is not influenced by the use of covers. Pool circulation pumps remain on continuously to maintain thermal and chemical mixing even though the boiler is not on.

Fans represent major electrical consumption, however, and are used less with reduced evaporation rate. The theoretical difference in fan usage relates to the difference in ventilation air requirements, the "AMFc" values in table IV. This in turn related directly to the reduction in evaporation rate from the pool due to cover usage. Pool facilities typically have more fan operation than this minimum however. The most wasteful case is when fans, sized to meet ventilation codes or an active pool conditions, are left running continuously at night or when a cover is on. This was initially the condition at Skyland, although there was manual switch control for fan reduction during the closed periods.

Three fans are used in the Skyland ventilation system as discussed earlier; a 10 kw main supply/circulation fan as part of a packaged roof air supply unit, and two 1 kw exhaust fans. Fan operation was adjusted to nearly minimum air flow through control change and addition. That is the addition of humidity control and also a control change on the main supply/recirculation fan operate on only if outdoor air is required or if heating is required(or both). This control strategy is possible during closed hours when there is not a minimum ventilation code requirement. The only departure from truly minimum fan usage with this system was due to a variable output air heater(natural gas burners). Instead of full capacity on/off operation, this unit provides heating as low as 20% of maximum output under low heating demand, thus prolonging the supply air fan operation.

Following the completion of the heating energy observations, two well controlled and monitored tests were conducted to compare fan power with and without the cover in place. The test consisted of measuring the running times of fans totaled over the twelve hours closure periods and multiplying them by the power of the motors. This resulted in a total electrical energy comparison of 3.3 KWH/hr for the cover off vs 0.2 KWH/hr for the cover on. The exhaust fan alone resulted in 0.97 KWH/hr for the cover off and 0.23 KWH/hr for the cover on; a 76 percent reduction.

Fan usage needs to be monitored over a full year to understand this savings potential more accurately. Without more fan energy test results, it is suggested to use the exhaust fan ratio only as a guide to the electrical power savings. Until more data are available, it is suggested that electrical savings be conservatively estimated as applicable to exhaust fan operation only. A rough estimate of savings therefore is 0.7 Kw for the annual covered hours, approximately 3500 Kwh, with a value of about \$200.

Annual Pool Cover Savings

Pool Water Heating

At uniform water temperature, air temperature, and air humidity, gas use resulting from evaporation is not affected by location or seasonal conditions. Therefore the annual gas use for the covered pool can be found simply by multiplying the hourly values found under the test conditions times the total yearly closed hours(5252 at the Skyland facility). The same procedure can be done for the uncovered pool, given that there is no activity in the water during closed times to affect the evaporation rate.

Table III shows average gas fuel use for pool water heating of 81 cubic feet per hour when the pool is covered and 444 cubic feet per hour when uncovered and not occupied. If covered 5252 hours per year, the corresponding annual gas uses are 4,254 and 23,319 ccf (hundred cubic feet) respectively. Pool covers therefore reduce gas requirements for pool water heating by 19,065ccf per year.

Air Heating

Fuel use for ventilation heating depends upon outdoor temperatures and humidities, both of which undergo hourly, daily and season variation. Projections of annual requirements by use of measurements of only limited duration and specific conditions therefore must be based upon statistical average weather data and the results of the tests. The days of each month are first divided into three periods, 12:00 to 8:00 am, 8:00 am to 4:00 pm, and 4:00 pm to 12:00. The monthly average temperature and humidity(dew point temperature) in each period are used to calculate the minimum ventilation air requirement and ventilation heating (equations (b) and (c)).

This method was performed for the Skyland pool location (Denver) and taking into account the normal time of closing (7 pm to 7 am). Historical averages of outdoor temperatures and humidity were found for each month using weighting factors of one-third from the 4:00 pm to midnight values and two-thirds from the midnight to 8:00 am values. The procedure is presented in Table V in a spread sheet format, each row containing monthly values.

Fuel use for ventilation air heating as shown in Table IV, is much higher in the cold winter months than in milder weather. Actual measurements in March and April show usage slightly higher than the monthly averages. Table V shows the

total gas use for air heating in the unoccupied natatorium would be 31,932 ccf if the pool is not covered, and 7178 ccf if covered 5252 hours per year. A savings of 26,680 ccf, combined with a 19,065 ccf savings for pool water heating, provides an annual total savings of 45,745 ccf. It should be noted that energy projections and savings apply only to periods when the pool is not in use, and therefore can be covered. Gas consumption during periods of active pool use is in addition to the figures herein.

Values in Table V are based on historical average atmospheric temperature and humidity in Denver, Colorado, (TMY data), and are represented as follows:

Dry Bulb-Average monthly temperature obtained by method described above, degrees F

Wet Bulb-Average monthly wet bulb temperature obtained by method described above, degrees F

Humid Ratio-Ratio of water to dry air(absolute humidity) found from the psychrometric chart or tables using the wet and dry bulb temperatures, lb water/lb dry air

Humid Dif-The humidity ratio of indoor air at 80 degrees F and 50 percent relative humidity (0.128) minus the monthly average outdoor humidity ratio, lb water/lb dry air

Temp Dif-Temperature difference between room test condition and monthly average dry bulb temperature, degree F

Air Volume Ratio- The air flow mass ratio between test conditions and the monthly average based upon humidity differences and equation (b). Monthly average Humid Dif divided by the test condition humidity difference, non-dimensional

Heat Ratio-The ratio of monthly air heating to the test air heating obtained as the Air Volume Ratio times the monthly average Temp Dif divided by the test condition temperature difference and equation (c), non-dimensional

Gas ccf-The monthly gas use determined from the hourly test gas use times the Heat Ratio and times the closed hours each month(438), hundred cubic feet/month

Projected annual gas requirements and savings resulting from use of pool covers are also presented in Figure 8. Annual gas use for pool water heating and for air heating during closed periods if the pool is covered and if not covered is indicated. Total gas savings as shown by the bar at the extreme right is nearly 41,000 ccf per year.

Table V

**Prediction of Annual Energy Use at Skyland
During Periods When Pool is Not in Use**

Calculation of Monthly and Annual Gas Use								
At the Skyland Swimming Pool								
Relative to Cover ON Test Results								
Month	Dry	Wet	Humid	Humid	Temp	Volume	Heat	Gas-ccf***
	Bulb	Bulb	Ratio	Dif*	Dif*	Ratio**	Ratio**	
Jan	25	20	0.0013	0.0117	55	0.58	1.07	713
Feb	29	26	0.0023	0.0107	51	0.64	1.08	723
Mar	34	29	0.0027	0.0103	46	0.66	1.01	677
Apr	43	36	0.0038	0.0092	37	0.74	0.91	610
May	52	44	0.0054	0.0076	28	0.89	0.84	559
June	62	53	0.0082	0.0048	18	1.42	0.85	569
July	67	55	0.0085	0.0045	13	1.51	0.65	438
Aug	65	53	0.0076	0.0054	15	1.26	0.63	421
Sept	56	46	0.0057	0.0073	24	0.93	0.75	498
Oct	46	34	0.0028	0.0102	34	0.67	0.76	505
Nov	33	30	0.0034	0.0096	47	0.71	1.11	742
Dec	29	26	0.0023	0.0107	51	0.64	1.08	723
						Total for air		7178
* Based on 80 degree and 50% RH air						Water heating		4254
** Relative to test conditions.						Total Annual ccf		11432
***During closed periods only								

Calculation of Monthly and Annual Gas Use								
At the Skyland Swimming Pool								
Relative to Cover OFF Test Results								
Month	Dry	Wet	Humid	Humid	Temp	Volume	Heat	Gas-ccf***
	Bulb	Bulb	Ratio	Dif*	Dif*	Ratio**	Ratio**	
Jan	25	20	0.0013	0.0117	54	0.81	1.25	3220
Feb	29	26	0.0023	0.0107	50	0.89	1.27	3260
Mar	34	29	0.0027	0.0103	45	0.92	1.19	3048
Apr	43	36	0.0038	0.0092	36	1.03	1.06	2730
May	52	44	0.0054	0.0076	27	1.25	0.96	2478
June	62	53	0.0082	0.0048	17	1.98	0.96	2471
July	67	55	0.0085	0.0045	12	2.11	0.72	1860
Aug	65	53	0.0076	0.0054	14	1.76	0.70	1809
Sept	56	46	0.0057	0.0073	23	1.30	0.86	2198
Oct	46	34	0.0028	0.0102	33	0.93	0.88	2257
Nov	33	30	0.0034	0.0096	46	0.99	1.30	3343
Dec	29	26	0.0023	0.0107	50	0.89	1.27	3260
						Total for air		31932
* Based on 80 degree and 50% RH air						Water heating		23319
** Relative to test conditions.						Total Annual ccf		55251
***During closed periods only								

Figure 9 shows the annual dollar value of fuel used and saved at Skyland with and without pool cover use. At the comparatively low gas price of \$0.29 per hundred cubic feet (ccf), the total cost of fuel for the uncovered pool during 5252 closed hours per year, based on normal Denver weather conditions, is projected at \$16,000. If the pool is covered during those periods, the cost decreases to \$3,300, thereby offering an annual savings of \$12,700. The relative cost and savings for water heating and air heating are also indicated.

Figure 8-Predicted annual gas use at Skyland

Figure 9-Predicted annual cost savings at Skyland by using covers.

Conclusions and Comments

Swimming pool covering when not in use is a highly effective method of saving energy. Evaporation is reduced by approximately 85%, depending upon the pool coverage ratio, typically 90-95%, and the extent of wetted cover surface, typically 5-10%. There are small amounts of convection, radiation, and equipment energy losses balanced against some circulating pump work supplied to the water. Noting all of these factors, the 81 percent measured fuel savings for pool water heating using a cover can be expected. Modest gains could be made by lowering the water temperature and avoiding water on the cover.

Ventilation air heat savings due to covering represented a lower percentage (74%) than for water heating, however the magnitude of the savings was greater. The ventilation requirements depend upon climatic location and can be found for different cities using the RSPEC computer software package.

Electrical power savings for fans was estimated, with a limited amount of testing, to be approximately 75 percent when pools are covered. This, as well as ventilation heating, can only be realized however when humidity and fan operation are properly controlled.

Results of the Skyland pool energy analysis can be projected to different pool operating conditions and in different locations through use of the US Department of Energy RSPEC software. The Skyland results agree closely with RSPEC values using temperatures, humidity, and other conditions which existed at the site. Water heating energy values were very close to RSPEC calculations(Figure 7). Air heating measurements were higher than predicted by RSPEC calculations. This is simply because there was often more ventilation (outdoor) air entering the facility than the minimum needed to remove humidity. The air heating measurements also include wall and window transmission losses which are not included in the RSPEC numbers because they are derived from ventilation air energy losses only.

Economic figures are shown here for a specific case at the Skyland pool facility. They are conservative in view of quite low energy prices at the site. Also the figures are variable for different locations and pool operating conditions. This study focused on energy cost factors. Savings in chemical for pool water treatment(known to be significant) or in building maintenance expense due to the covers providing lower natatorium humidity have not been estimated. Maintenance costs on the covers themselves were not available for this analysis.

Appendix A

Plan View of Skyland Swimming Pool (Provided by Lof Energy Systems, Inc.)

Appendix B

Calculation of evaporation energy rate was done by computer using equation (a):

$$PHc = (71.4 + .38 * v) * (P_w - P_a)$$

Where: PHc- modified ASHRAE evaporation energy rate, btu/hr-sq ft

v- air velocity over water surface, ft/min

P_w -saturation vapor pressure at the water temperature, in. Hg

P_a -saturation vapor pressure at the air dewpoint, in. Hg

The following is an example calculation for conditions of:

Pool water temperature of 80 degrees F

Pool room air temperature of 80 degrees F

Pool room air humidity of 50 percent

Average air movement over the pool(v) of 5 ft/min

Vapor pressure values are found from ASHRAE Fundamentals

Handbook(Psychrometrics, Chapter 6, 1993) tables or ideal gas law calculations to be:

$$P_w = 1.033 \text{ in. Hg}$$

$$P_a = 0.550 \text{ in. Hg}$$

Thus:

$$PHc = (71.4 + .38 * 5) * (1.033 - 0.550) = 35.7 \text{ Btu/hr-sq ft}$$

The computer takes temperature and humidity measurements and performs this calculation each 0.1 hour (6 minutes) yielding an energy quantity of one tenth; for the case above, 3.57 Btu/sq ft. Then, for example, if the computer repeats the time step calculation 120 times (twelve hours) for a total of 480 Btus/ sq ft, the hourly evaporation energy rate for the period is:

$$PHc = 480 / 12 = 40 \text{ Btu/hr-sq ft}$$

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