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Mad Dog
DESIGN & CONSTRUCTION inc.

12-0414

FINAL REPORT DEPARTMENT OF ENERGY GRANT #DE-FG-44-80R410131

SOLAR LUMBER KILN

THE PURPOSE OF THIS PROJECT WAS TO ESTABLISH DESIGN PARAMETERS FOR THE CONSTRUCTION OF SMALL SCALE (1,000 BOARD FOOT CAPACITY) LUMBER DRYING KILN WHICH DERIVES ITS THERMAL ENERGY FROM THE SUN. THE DESIGN CONCEPTS WERE MODIFIED FROM A CONSIDERABLE BODY OF WORK PERFORMED ON SOLAR WOOD DRYING TO UPGRADE THE ABILITY OF THE KILN TO SELF-REGULATE AND INSULATE ITS SOLAR APERTURE IN ORDER TO ACHIEVE HIGHER AND MORE STABLE KILN CHAMBER TEMPERATURES, AND AN EXTENDED PERIOD OF OPERATION. THESE ADVANCES ARE TO ENHANCE THE COST EFFICIENCY OF SUCH A KILN.

THESE RESULTS BASED ON A SIX MONTH MONITORING PERIOD, TOGETHER WITH SECOND GENERATION DESIGN CONSIDERATIONS AND SIMPLIFIED CONTROL LOGIC ARE PRESENTED IN THIS REPORT.

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DESIGN PARAMETERS

ORIGINAL DESIGN PARAMETERS WERE BASED ON THE FOLLOWING ASSUMPTIONS; (1) IN THE SUMMER, HIGH AMBIENT TEMPERATURES COUPLED WITH HIGH LEVELS OF INSOLATION WILL PROVIDE ADEQUATE DRYING TEMPERATURES WITH MINIMAL DIRECT INSOLATION ON THE STORAGE MASS. (2) OPTIMUM DRYING CONDITIONS WILL OCCUR IN THE MONTHS FROM OCTOBER THROUGH JANUARY DUE TO RELATIVELY LOW AMBIENT HUMIDITIES COUPLED WITH HIGH AFTERNOON TEMPERATURES. (3) HEAT LOSS FROM THE KILN CHAMBER WILL BE LIMITED LARGELY TO LATENT AND SENSIBLE HEAT LOADS REMOVED FROM THE KILN CHAMBER DUE TO INTRODUCTION OF AMBIENT AIR FOR HUMIDITY CONTROL. (4) THE LOWER SUN ANGLE WILL PRODUCE GOOD PENETRATION OF INCIDENT RADIATION.

WOOD DRYING

THE DRY KILN OPERATOR HAS THREE VARIABLES TO CONTROL WHICH AFFECT THE QUALITY OF LUMBER FROM THE DRYING PROCESS. THEY ARE THE AIR CIRCULATION RATE, THE RELATIVE HUMIDITY AND THE DRY BULB TEMPERATURE. A TYPICAL DRYING OPERATION WILL BEGIN WITH THE MILLING OF THE SUBJECT LUMBER INTO THE SMALLEST APPROPRIATE SIZE. THE SMALLER THE LUMBER, THE MORE EASILY IT IS DRIED. THIS LUMBER IS THEN STACKED WITH SPACERS BETWEEN EACH BOARD AND PLACED IN A

SHED FOR AIR DRYING. AIR DRYING REMOVES A LARGE AMOUNT OF THE CELLULAR WATER, AND SHORTENS KILN RESIDENCE TIME. IT IS LEFT TO THE KILN TO THEN REMOVE WATER WHICH IS BOUND WITHIN THE CELLULAR STRUCTURE OF THE MATERIAL ITSELF. FOR HIGH QUALITY FURNITURE GRADE HARDWOODS, IT IS IMPERATIVE THAT THIS WATER BE REMOVED IN AN EVEN MANNER. TEMPERATURE AND MOISTURE DIFFERENTIALS BETWEEN THE SURFACE AND THE INTERIOR OF THE WOOD CREATE THE STRESSES WHICH RESULT IN CHECKING, WARPING AND CUPPING THE BOARDS. THE IDEAL BOARD UPON REMOVAL FROM THE KILN WOULD HAVE A MOISTURE CONTENT OF 8% OR LOWER AND BE RELAXED THROUGHOUT. SUCH LUMBER WORKS WELL AND WILL MAINTAIN ITS DIMENSIONAL STABILITY FOR MANY YEARS.

IN A COMMERCIAL KILN, ALL THREE VARIABLES ARE PRECISELY CONTROLLED IN AN EFFORT TO MINIMIZE RESIDENCE TIME WITHIN THE KILN. THIS IS NECESSARY TO OFFSET LARGE CAPITALIZATION AND OPERATING COSTS. FOR THE SMALL SCALE LUMBER DRYER, THE ABILITY TO CONTROL HUMIDITY AND TEMPERATURE IS RELATIVELY COARSE. AIR CIRCULATION RATE MAY BE EASILY VARIED. IT IS BEYOND THE SCOPE OF THIS WORK TO ESTABLISH THE VARIOUS PARAMETERS FOR THE SUCCESSFUL OPERATION OF THE KILN. IT WAS OUR ATTEMPT TO VALIDATE TEMPERATURES ACHIEVABLE BY THE KILN, PROVIDE A SIMPLIFIED DESIGN SUITABLE FOR SMALL SCALE OPERATIONS AND TO PROVIDE A LOOK AT A SECOND GENERATION SOLAR KILN.

EXPERIMENTAL PROCEDURE

TEMPERATURE SENSORS WERE LOCATED WITHIN THE WATER DRUM STORAGE MASS, THE FLOOR SLAB STORAGE MASS, THE FLOOR SLAB EDGE, THE KILN CHAMBER AND THE "SKY WINDOW". A RADIANT TEMPERATURE INDICATOR WAS ADDITIONALLY LOCATED WITHIN THE SKYWINDOW. A STRIP CHART RECORDER CAPABLE OF MONITORING THESE STATIONS WAS LOCATED WITHIN THE INSTRUMENT ROOM ADJACENT TO THE KILN. INSTRUMENTS DESIGNED AT THE FLORIDA SOLAR ENERGY CENTER TO MEASURE RELATIVE HUMIDITY INSIDE AND OUTSIDE THE KILN WERE ALSO PLACED IN THEIR APPROPRIATE LOCATIONS. A DIFFERENTIAL TEMPERATURE MONITOR MEASURES THE RADIANT SKY TEMPERATURE IN THE "SKY WINDOW" AND EVALUATES IT AGAINST THE TEMPERATURE OF THE STORAGE MASS IN THE WATER DRUM. WHEN THE SKY RADIANT TEMPERATURE EXCEEDS THE WATER DRUM TEMPERATURE BY 10 DEGREES, A MOTOR IS OPERATED TO OPEN THE INSULATING DOOR COVERING THE SOLAR APERTURE. A TEMPERATURE DIFFERENTIAL OF LESS THAN 10 DEGREES RE-ACTIVATES THIS MOTOR AND THE KILN DOOR IS CLOSED. DELAYS IN OBTAINING INSTRUMENTS RESULTED IN INITIATING DATA ACQUISITION LATER IN THE YEAR THAN WAS ORIGINALLY PLANNED. DATA WAS COLLECTED FOR THE MONTHS OF FEBRUARY AND MARCH AND PROCESSED WITH THE FOLLOWING RESULTS;

(1) THE PRIMARY THERMAL MASS, COMPOSED OF 25, (55 GALLON) 208.1 WATER DRUMS, WAS INITIALIZED AT A TEMPERATURE OF 16.1 DEGREES CENTIGRADE. THIS STORAGE MASS GAINED APPROXIMATELY .3 TO .6 DEGREES CENTIGRADE (1 1/2 TO 2 DEGREES FAHRENHEIT) PER DAY THROUGH A PERIOD OF MODERATE SOLAR INSOLATION AND COOL EVENING

TEMPERATURES IN FEBRUARY AND MARCH REACHING A TEMPERATURE PLATEAU OF 24 DEGREES CENTIGRADE (75 DEGREES FAHRENHEIT). THROUGH APRIL, THIS TEMPERATURE HAD NOT RISEN ABOVE 25.5 DEGREES CENTIGRADE.

(2) TEMPERATURE SENSORS LOCATED IN THE CENTER OF THE FOUNDATION SLAB AND AT THE EDGE OF THE FOUNDATION HAVE INDICATED SUBSTANTIAL HEAT LOSS OCCURING THROUGH THE SLAB EDGE. (3) THE TWO RELATIVE HUMIDITY SENSORS, ONE LOCATED INSIDE THE KILN CHAMBER AND ONE LOCATED OUTSIDE THE INSTRUMENT ROOM, ARE INSUFFICIENT FOR THEIR PURPOSE OF OPERATING AN AIR EXCHANGE FAN TO CONTROL INTERNAL HUMIDITY. (4) THE REFLECTIVE INSULATING SHUTTER WHICH WAS DESIGNED TO ENHANCE SOLAR GAINS WILL REQUIRE MONTHLY, PERHAPS WEEKLY ADJUSTMENT DURING THE SUMMER TO MAINTAIN A CORRECT ANGLE OF REFLECTION SO THAT THE ANGLE OF INCIDENCE ON THE GLAZING SURFACE WILL ALLOW MAXIMUM TRANSMISSION. OUR ORIGINAL DESIGN DID NOT ALLOW FOR THIS ADJUSTMENT.

WE MADE MANUAL ADJUSTMENTS OF THE REFLECTING SHUTTER, INCREASED THE FLOOR SLAB PERIMETER INSULATION, REPLACED THE TWO HUMIDITY SENSORS WITH A SIMPLE TIMER FOR OPERATION OF THE AIR EXCHANGE FAN, AND MONITORED THE KILN FOR AN ADDITIONAL FOUR WEEKS. WE THEN BEGAN A NEW PERIOD OF DATA ACQUISITION DESIGNED TO PINPOINT AND QUANTIFY THE PROBLEMS OUTLINED ABOVE.

THE RESULTS OF THIS MONITORING ARE SUMMARIZED BELOW;

1. WHILE THE SHUTTER ADJUSTMENT DID HELP, THE BASIC SHIFT OF THE SUN TO THE NORTH COUPLED WITH ITS INCREASED ALTITUDE RESULTED IN AN ANGLE OF INCIDENCE SUFFICIENT TO ELIMINATE A MAJOR PORTION OF

RADIANT GAIN FROM THE KILN. THIS BASIC FACT PREVENTED THE KILN FROM ACHIEVING TEMPERATURES SIGNIFICANTLY GREATER THAN AMBIENT AVERAGES.

2. BECAUSE OF FACTOR 1 ABOVE, HIGH TEMPERATURE DIFFERENTIALS FROM THE INSIDE TO OUTSIDE OF THE KILN WERE NOT OBTAINABLE AND THEREFORE THE RESULTS OF INCREASED PERIMETER INSULATION COULD NOT BE MEASURED.

3. THE TIMER PERFORMED ADEQUATELY FOR HUMIDITY CONTROL WITHIN THE KILN CHAMBER.

LATEST RESULTS

THE SEASONAL SHIFT OF SUN BACK INTO THE SOUTHERN SKY HAS RESULTED IN DRAMATIC INCREASE IN PERFORMANCE OF THE KILN. THIS IS ALTOGETHER EXPECTED IN AS MUCH AS TRANSMISSION OF SOLAR ENERGY THROUGH THE GLAZING INCREASES VERY RAPIDLY AT ANGLES OF INCIDENCE LESS THAN 70 DEGREES. THE LATEST EXPERIMENTAL DATA HAS CONFIRMED SEVERAL OF OUR EARLIER HYPOTHESIS. (1) INCREASED SLAB PERIMETER INSULATION EFFECTIVELY REDUCES HEAT LOSS THROUGH THE SLAB EDGE. IT SHOULD BE NOTED THAT KILN TEMPERATURES ARE NOW AVERAGING 46 DEGREES TO 55 DEGREES CENTIGRADE (115 DEGREES TO 130 DEGREES FAHRENHEIT). THIS VERY HIGH TEMPERATURE DIFFERENTIAL RESULTS IN A SUBSTANTIAL DRIVING FORCE ACROSS THE SLAB INSULATION TO THE

INFINITE THERMAL MASS OF THE GROUND. WITH PERIMETER INSULATION BOOSTED FROM 2.5 CM TO 10.16 CM (1 INCH TO 4 INCHES), TEMPERATURE DIFFERENTIALS FROM THE CENTER OF THE SLAB TO THE OUTSIDE EDGE OF THE SLAB HAVE BEEN LESS THAN $1/3$ DEGREES CENTIGRADE. THIS INDICATED THAT WE HAVE SUCCESSFULLY CREATED BOUNDARY CONDITIONS AT THE SLAB EDGE SIMILAR TO THOSE BENEATH THE CENTER OF THE SLAB. WE HAVE RECORDED AIR TEMPERATURES WITHIN THE SKY WINDOW OF OVER 71 DEGREES CENTIGRADE (160 DEGREES FAHREINHEIT). TEMPERATURES WITHIN THE KILN CHAMBER ITSELF HAVE YET TO EXCEED 51 DEGREES CENTIGRADE (125 DEGREES FAHRENHEIT) AND THE WATER DRUM STORAGE TEMPERATURE HAS LAGGED SIGNIFICANTLY.

CONCLUSIONS

1. THE MECHANICAL CLOSER CAN BE ELIMINATED. THERE IS REMARKABLE CONSISTENCE IN THE AUTOMATIC OPERATION OF THE REFLECTIVE DOOR SHUTTER. EVERY DAY THAT CAN BE CLASSIFIED AS "SUNNY", THE KILN DOOR CLOSED AT APPROXIMATELY THE SAME TIME. MOST EVERY DAY WHICH STARTS AS "CLOUDY OR OVERCAST" RESULTS IN INSUFFICIENT PERIODS WITH THE DOOR OPEN TO WARRANT THE AUTOMATIC OPENING AND CLOSING OF THE SHUTTER. THIS MEANS THAT TWO LOWER COST ALTERNATIVES TO AUTOMATIC OPERATION OF THE INSULATED SHUTTER ARE POSSIBLE. (A) A SHUTTER COULD BE CONSTRUCTED FOR MANUAL OPENING AT THE BEGINNING OF A "SUNNY" DAY WITH A COUNTER BALANCE TO CLOSE THE DOOR ON A TIMER IN THE EVENING. THIS REPRESENTS A LEAST COST APPROACH IN THAT IT WOULD REQUIRE NO ELECTRIC MOTOR, NO DIFFERENTIAL

THERMOSTAT, AND NO LOW VOLTAGE SYSTEM TO OPERATE THE MOTOR. OUR DATA INDICATED THAT SUCH A SYSTEM WOULD SACRIFICE ONLY marginally IN THERMAL PERFORMANCE FOR COST SAVINGS OF ABOUT \$1800.00. (B) AND OPERATOR SIMILAR TO THE ONE WHICH WE HAVE INSTALLED TO BE USED AND SET FOR CLOSINGS ON TIMER AND MANUALLY ACTIVATED TO OPEN IN THE MORNING. THIS SYSTEM WOULD RESULT IN INCREMENTAL SAVINGS OF THE DIFFERENTIAL THERMOSTAT, APPROXIMATELY \$150.00.

2. EXCESSIVE STORAGE MASS IS HAMPERING PERFORMANCE. BECAUSE OF THE TEMPERATURE DIFFERENTIAL WITNESSED BETWEEN THE WATER DRUM STORAGE MASS, THE SKY WINDOW AND THE AIR TEMPERATURE INSIDE THE KILN, IT IS APPARANT THAT THE DESIGN IS OVERMASSSED. THE POSITIVE BENEFITS OF THIS EXCESSIVE MASS IS EXTRAORDINARY TEMPERATURE STABILITY WITHIN THE KILN CHAMBER. THE NEGATIVE ASPECT IS THAT IT PREVENTS HIGH KILN TEMPERATURES FROM BEING ACHIEVED. WE NOW THINK THAT AN AIR COLLECTOR IN PLACE OF MASS-TROMB WALL WOULD ACHIEVE HIGHER TEMPERATURES AT THE EXPENSE OF SOME THERMAL STABILITY, BUT THAT THIS WOULD BE A BENEFICIAL TRADE-OFF. INITIAL COST SAVINGS IN CONSTRUCTION COULD BE EXPECTED DUE TO THIS CHANGE.

3. CIRCULATING FANS USE TOO MUCH ENERGY. THERE ARE THREE ELECTRICALLY DRIVEN FANS WHICH CIRCULATE AIR FROM THE COLLECTOR CHAMBER INTO THE KILN CHAMBER THROUGH THE LUMBER CHARGE AND BACK INTO THE COLLECTOR AREA. THESE FANS ARE THERMOSTATICALLY ACTIVATED IN A CASCADE FASHION. FAN NUMBER 1 COMES ON AT 90 DEGREES, FAN NUMBER 2 AT 105 DEGREES, AND FAN NUMBER 3 AT 120

DEGREES. WHEN ALL THREE OF THESE FANS ARE OPERATING, THE KILN CONSUMED ABOUT 600 KILOWATTS A MONTH. WHILE THIS REPRESENTS A MODEST EXPENSE FOR A COMMERCIAL DRYING OPERATION, WE FEEL THAT IT IS INCONSISTENT WITH THE THRUST OF THE DESIGN.

NEXT GENERATION DESIGN

BASED ON OUR EXPERIENCES AND ON RESEARCH BY OTHERS, WE NOW THINK THAT THE MOST EFFICIENT KILN DESIGN WILL BE AN ISOLATED AIR COLLECTOR COUPLED PASSIVELY TO AN INSULATED CHAMBER. BACK DRAFT DAMPERS WOULD PREVENT REVERSE COOLING OF THE KILN DURING COLD WEATHER AND STRONG SOLAR INSOLATION WILL PROVIDE THE DRIVING FORCE TO HEAT THE KILN AND TO CIRCULATE THE AIR WITHIN THE KILN. THIS WOULD ELIMINATE THE NEED FOR THE INSULATING REFLECTIVE SHUTTER AND ALLOW FOR A SLOPED GLAZING SURFACE FOR THE AIR COLLECTOR WHICH WILL MAXIMIZE PERFORMANCE BOTH FOR SUMMER AND WINTER.

PERIPHERAL ISSUES WHICH HAVE RECEIVED CLARIFICATION BY THIS PROJECT INCLUDE: (1) A DEMONSTRATION OF THE FACT THAT GLAZING MATERIALS CAN AND DO PERFORM AS THEIR OWN SHADING DEVICES WHEN THE ANGLE OF INCIDENCE IS SUCH THAT SOLAR TRANSMISSION IS SIGNIFICANTLY REDUCED. (2) RELATIVELY LOW LEVELS OF PERIMETER INSULATION 2.5 TO 4 CM (1 TO 1 1/2 INCHES) ARE EFFECTIVE IN REDUCING SLAB LOSS FOR RELATIVELY LOW TEMPERATURE DIFFERENTIALS 11.22 DEGREES CENTIGRADE OR LESS (30 DEGREES FAHRENHEIT OR LESS).

RECCOMENDATIONS

IT IS APPARENT FROM THIS PROJECT THAT SMALL SCALE COST EFFECTIVE LUMBER PROCESSING MAY BE PERFORMED BY SOLAR ENERGY. THE COMMERCIAL APPLICABILITY OF THIS TYPE OF PROCESSING IS DOUBTFUL DUE TO THE INHERENT LIMITATIONS OF THE ENERGY SOURCE. THE ENERGY CONSERVATION AND SOLAR UTILIZATION ASPECTS OF THIS PROJECT MAKE IT ESPECIALLY USEFUL FOR APPLICATION IN SECONDARY EDUCATION AND VOCATIONAL TECHNICAL SETTINGS.

MATERIALS, EQUIPMENT AND DRAWINGS;

SEE ATTACHMENTS

Natural Power Inc.FRANCESTOWN TURNPIKE
NEW BOSTON, NH 03070
(603) 457-5512

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MAD DOG DESIGN & CONSTRUCTION
Box 12261
Tallahassee, FL 32308

SAME

PHONE: ~~XXXXXXXXXX~~ 904-878-5285

APPROVED BY:

CUST. PURCH. ORDER #	PURCHASE ORDER DATE	DATE RECEIVED / BY (NPI)	REQUEST. DELIV.	PROD. PROG.
T. Barr	7-14-80	7-14-80SC	asap	stock
ESTIMATED SHIP DATE: August 7, 1980 item 2 Aug 15		F.O.B.: NEW BOSTON, NH	SHIP. CHRG.: PREPAY - BILL - COD	REQUEST ROUTING: UPS

ITEM	QTY.	MODEL # / DESCRIPTION
1	1	R10-201 Single channel recorder w/event marker
2	1	R70 Automatic sampling Switchw/adjustable dwell time
3	1	A95-002 Weather Housing for recorder
4	12	R90-100 Chart paper, single channel
5	1	S25-425 Differential Thermostat w/ collection inhibit on S2; (1)S92, (1)S93
6	2	S25-125 Differential Thermostat w/S92 sensors
7	1	S35-206 Temperature Monitor, 6-input (4) S92 sensors; 6'leads (2) S91 liquid sensors
8	1	S94 radiation sensor
9	10	S93 surface sensors

Less 10% initial discount on all items
except 4 (no discount on chart paper):

Item # 6 in this box

7/31/80

THIS SHIPMENT

PARTIAL

FINAL

White - Sales

Blue - Inv.

Gold - Acknowl.

Yellow - Acctg.

Green - Prod.

Pink - Pack

Gold - Prod.

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SOUTH

NORTH

WEST

EAST

PIAT

SOLAR LUMBER KILN

SCALE: 1/4" = 1'-0" DATE: 8/90 APPROVED BY: DRAWN BY: 8/90

MAD DOG DESIGN & CONST

16'

2x4 studs 24" oc. hinge at every stud

DOOR
REFLECTOR/INSULATING

SILL Vert. X-Section

SOLAR LUMBER KILN

SCALE: Varies	APPROVED BY:	DRAWN BY: 7B
DATE: 7/80		REVISED:
MAD DOB DESIGN & CONSTRUCTION		
DRAWING NUMBER:		

EXPLODED ISOMETR

of CLIP

SECTION of CLIP
INSTALLED ON BARRELS
ACTUAL SIZE

DRAFTED FROM WORK BY ZOME WORKS

SOLAR LUMBER KILN

SCALE:	APPROVED BY:	DRAWN BY: TB
DATE:	REVISED:	