ENVIRONMENTAL DESIGN OF A NEW BURLEY CURING BARN[1]

By JOE M. BUNN, GEORGE A. DUNCAN, WILEY H. HENSON, JR. and LINUS R. WALTON
Associate professor, Extension Specialist, Agricultural Engineer (USDA, ARS) and Agricultural Engineer (USDA, ARS), Agricultural Engineering Department, University of Kentucky, Lexington, Kentucky

From investigations into burley tobacco curing methods at the Kentucky Agricultural Experiment Station have evolved consideration of and criteria for a new curing structure. The structure is a two-tier forced-ventilation curing system utilizing higher loading densities than conventional barns. High loading densities reduce the barn volume needed per acre and aids in uniform air distribution under the forced-air system. A basic pole-frame trussed-roof design was used to provide more versatility and adaptability in the use of the structure.

Electrical controls for the ventilation system give more managerial control over the curing process. Other features of the forced-ventilation system reduce the effects of ambient environmental extremes and reduce the environmental gradients within the curing tobacco. The two-tier design and higher loading densities reduce the labor crew size and the total labor required to house tobacco, in the new burley tobacco curing barn.

INTRODUCTION

Burley tobacco is a major crop in Kentucky, representing 35-40% of the gross income from agriculture. Many production operations for burley tobacco are similar to those for other domestic tobaccos, with major deviations coming at the time of harvesting and curing. Traditionally, the whole plant is harvested, speared onto wooden sticks, field wilted, and then moved into a curing structure. These structures range in heights up to 20-30 ft., making the tobacco housing operation laborious, hazardous and requiring a large crew of workers.

Curing is accomplished over a four to six-week period by natural ventilation. Kentucky's climatic conditions are generally favorable for good natural curing. However, periods do occur when the tobacco either dries too fast or too slowly to keep pace with the chemical and biological changes in the tobacco needed for an acceptable cure. When natural ventilation is inadequate for proper curing, many different types of supplemental aids are used individually or in combinations. These aids range from heat-pots placed about under the tobacco to portable fans arranged to force air into or out of the curing structure.

To better answer the producers' questions about improved curing practices, investigations were started at the Kentucky Agricultural Experiment Station in the early 1960's (3, 4, 5) to learn the proper use of supplemental aids in burley tobacco curing. These studies grew to include not only types of aids, proper time of use, and proper location within the structure, but also the structure itself and how it influences the total housing and curing process (6, 7). Labor efficiency, work crew sizes, volume, cost, efficiency and other characteristics of the production process as influenced by the curing structure were investigated (see Duncan and Bunn, 2). From these studies evolved the design of a new burley tobacco curing structure. This paper presents some of the considerations that went into development of the design and some on-the-farm evaluations of barns constructed according to the design.

DESIGN CONSIDERATIONS

Even though most of the Kentucky studies were not directed explicitly at developing design criteria for a new curing facility, some of the findings in these studies indicated production practices could be improved with modified facilities. Some of the general conclusions reached were:

1. The market value of tobacco properly cured with forced ventilation was equivalent to that of tobacco cured by conventional methods.
2. Tobacco could be loaded to a higher volume-density (about 2 times as many stalks per unit volume) in a forced ventilation barn, thus reducing the barn size needed per acre of tobacco.
3. A reduction in barn size, accomplished by reducing the barn height, reduced the housing labor requirements and crew size needed to accomplish housing.
4. At the increased densities of barn loading used with forced ventilation, three or more tier levels gave unsatisfactory performance because of a drying front which developed within the tobacco.
5. With two-tier levels of tobacco, resistance to air flow was relatively small; i.e., a pressure drop in the range of 0.1 in. of water column at air flow rates of 12-15 CFM/sq. ft. of barn cross-section These air flow rates were found to give satisfactory curing results.
6. Supplemental heat could be more effectively used with forced ventilation than with conventional curing practices.
7. Direction of air flow, butts to tips or tips to butts, showed little difference at low to normal air flow, with a slight preference for flow from butts to tips for high air flow rates. Uniform air distribution through the tobacco was the most critical consideration.

[1]*The investigation reported in this paper (No. 72-2-47) is in connection with a joint project of the Kentucky Agricultural Experiment Station and the Agricultural Engineering Research Division, ARS, USDA, and is published with the approval of the Directors of the Station and the Division. Received: June 22, 1972. Tob. Sci. XVII: 1-5; 1973.*

From these conclusions and other general observations evolved criteria for a two-tier forced-ventilation curing system. New construction methods, long life, economical construction and operation were other de-

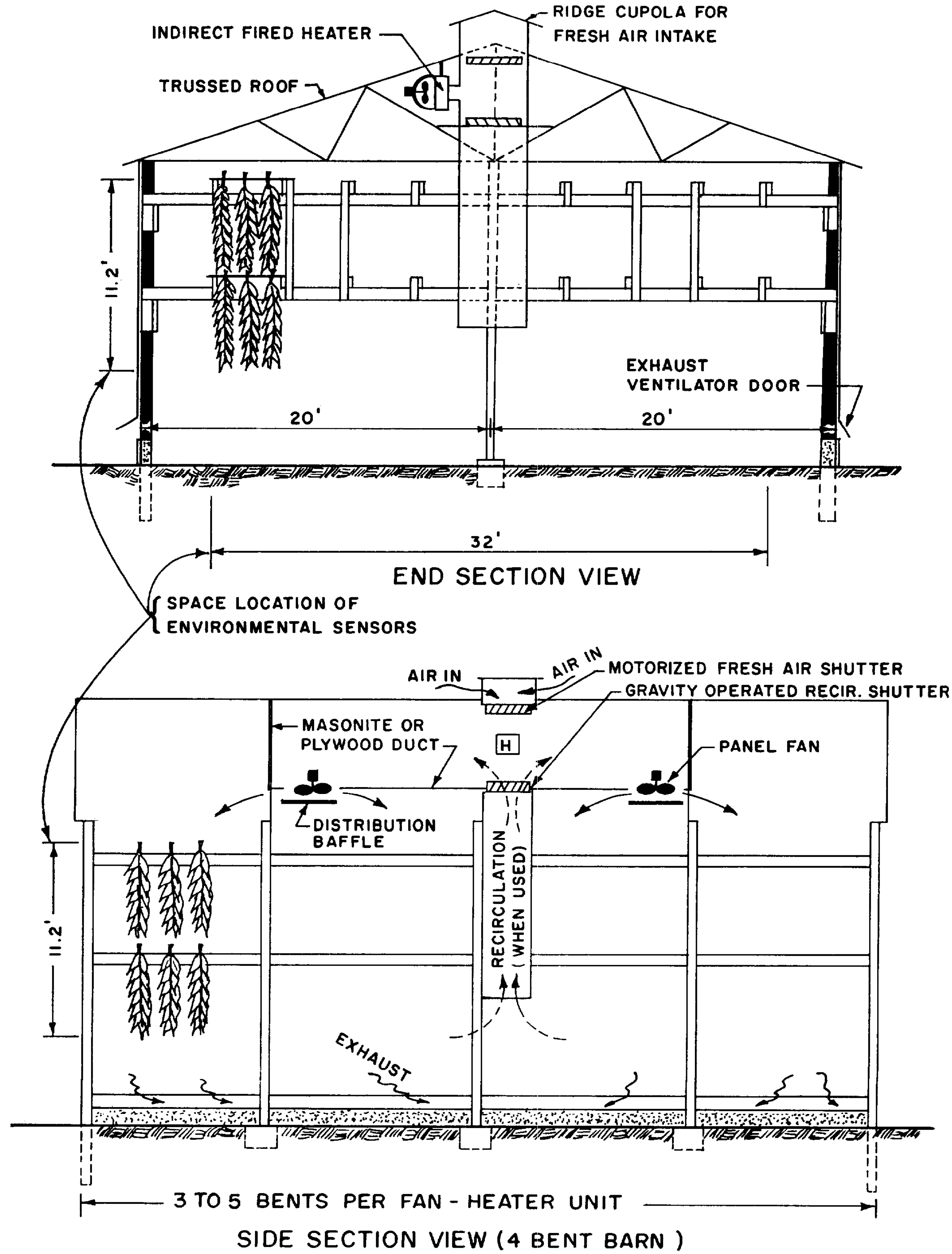

Figure 1. Sectional views of the two-tier forced ventilation burley tobacco curing barn.

Tobacco Science, 1973, 17-1, p. 1-5, ISSN.0082-4523.pdf

sign factors considered. Within these design criteria, a pole-frame clear-span structure was conceived.

THE BARN DESIGN

A basic pole-frame trussed-roof structural design was developed to provide versatility and adaptability. To provide for both large and small acreage producers, plans were developed in 32- and 40-ft. widths with 12 ft. long repeating bays or "bents." An eave height of 17 ft. was used to provide overhead clearance in the driveways and accommodate two tier-rails spaced 5½ ft. apart vertically. This vertical spacing minimized tobacco overlap yet kept the spacing within reasonable working heights. Horizontal tier-rail spacing was reduced from the traditional 48 inch to 38-40 inches for easier working conditions and better plant grid spacing under forced air curing.

The tier rails were designed to support a uniform load of 90 lbs. per linear foot (6 lb/plant, 6 plants/stick, and 5-inch minimum stick spacing). The supporting members, or cross-beams, and pertinent joints were designed to support the above load and transfer it to the pole structure. The tier rail system can be removed from the barn without affecting the basic structural design or strength. The roof, side, and end walls were designed air-tight to prevent air loss except for an 8- to 10-inch horizontal exhaust slot along the sidewall foundation. Hinged boards are used to close this exhaust opening when not needed for ventilation.

High-volume, low-pressure panel fans with adjacent gas-fired heating units were located in the gable space to bring in outside air, distribute it throughout the space, and force the air down through the tobacco to control moisture and temperature during the cure. Many different exhaust and pressure-type ventilation system characteristics were reviewed in developing a suitable air distribution design—an essential factor for success in this type facility. A diagonally positioned fan with a deflection-distribution baffle underneath appeared most practical and economical based on performance characteristics reported by Parker (9) and because of its widespread use in poultry and animal facilities. Figure 1 shows how the adaptation here utilized the baffle under the fan but without a ceiling boundary. The main air stream is directed out about half way to the walls where it hits and diffuses among the tobacco stalk butts extending approximately 12 inches above the top rail. The velocity energy of the air is then efficiently used for distribution, with accompanying turbulence providing air and heat mixing, while the overall static pressure forces the diffused air through the tobacco. The plywood baffle is square, with a side length 1.5 times the fan diameter, suspended 12 to 20 inches below the fan to give the desired air distribution. It is turned diagonally so that 20% more air discharging off the edge (Parker, 9) is directed toward the corners of the barn where a greater proportion of the air is needed to achieve equal distribution.

The fans are centered over a section of the barn, whose length is approximately equal to the barn width (40 x 36 ft. or 32 x 36 ft.) and are sized to provide 18-20 CFM per sq. ft. at 0.10-inch static pressure, AMCA rated. The unit heaters are sized to provide an 8 to 10°F temperature rise above the incoming air, (60-62°F, 85-90% r.h.), thus lowering the relative humidity of the air about 20%. The heat is injected into the fesh-air stream ahead of the fan so the ensuing fan blade action and other turbulence produces mixing. Two fans and one heater normally constitute a "system module" (**Figure 1**). Long barns utilize two or more modules operated independently in sections of the barn partitioned with thin plywood or fiberboard from the roof to the lower tier.

An optional air recirculation capability was also incorporated (see **Figure 1**). Two manually operated air control louvers or plywood flaps were installed near the fans to permit either fresh air intake (nor-

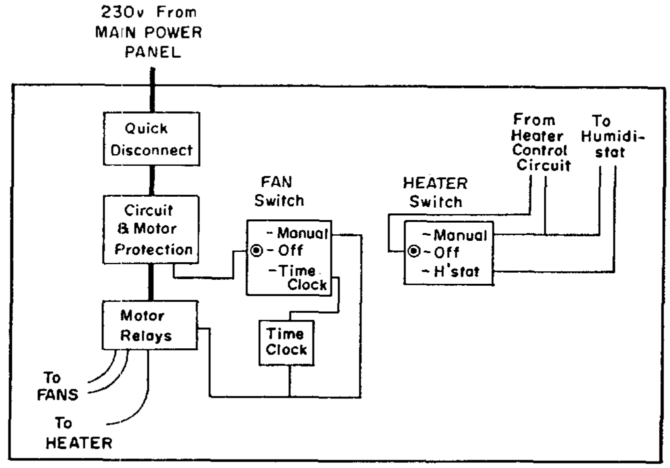

Figure 2. Block diagram of electrical controls for forced ventilation burley tobacco curing.

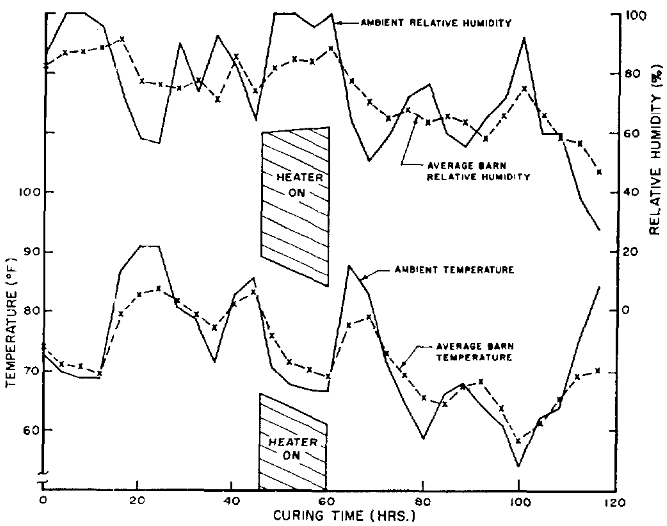

Figure 3. Average environmental conditions within two-tier forced ventilation burley tobacco curing barn compared with ambient conditions.

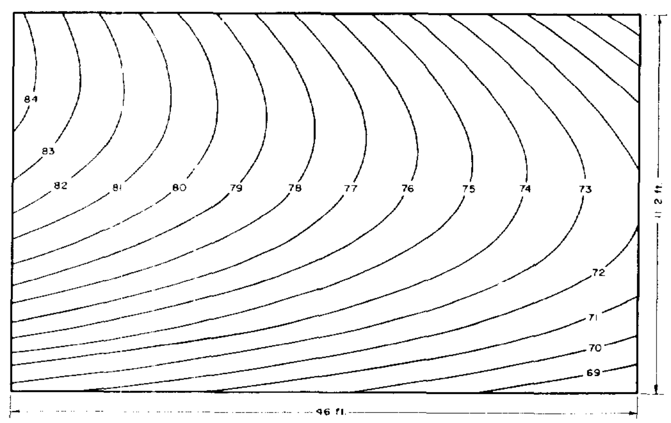

Figure 4. Side sectional view of temperature profile in two-tier forced ventilation burley tobacco curing barn for ambient temperature of 84°F and wind velocity of 5 mph.

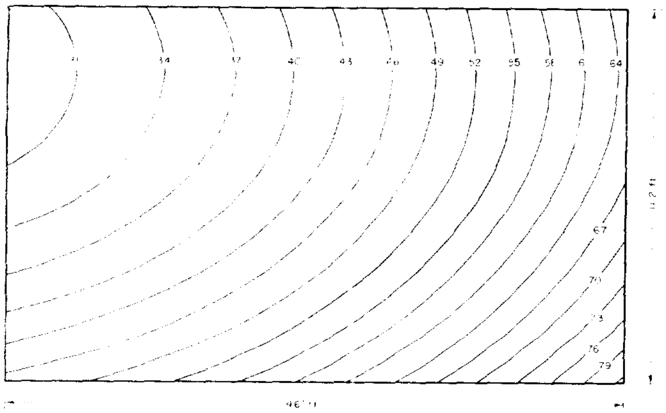

Figure 5. Side sectional view of relative humidity profile in two-tier forced ventilation burley tobacco curing barn for ambient relative humidity of 33.25% and wind velocity of 5 mph.

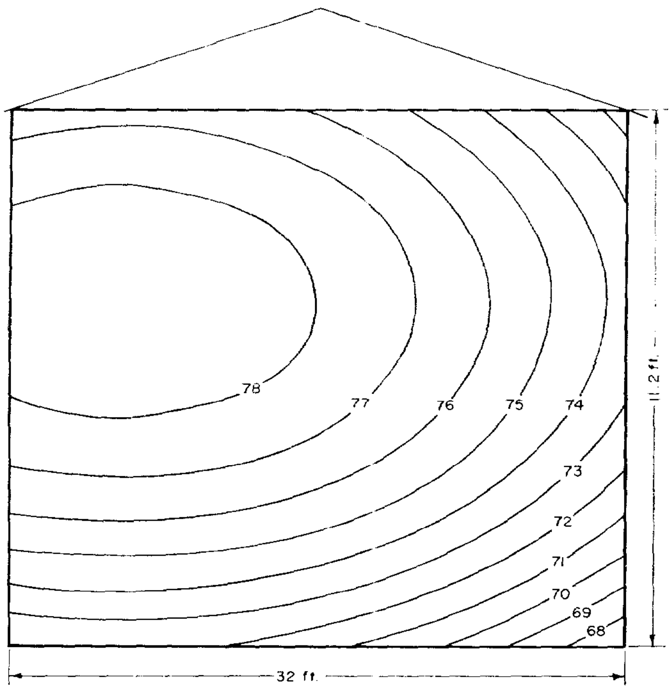

Figure 6. End sectional view of temperature profile in two-tier forced ventilation burley tobacco curing barn for ambient temperature of 84°F and wind velocity of 5 mph.

mal operation) or recirculation of interior air. In the recirculation mode, air from underneath the tobacco is ducted back up to the fans and again forced through the tobacco with very little exchange of air to the outside. Recirculation primarily enabled artificial casing of cured tobacco by adding moisture to the recirculated air. (Natural casing is achieved by drawing air from the outside during periods of high humidity.)

Electrical controls include a quick disconnect switch, fused circuit and motor protection, fan and heater selection switches, a time clock, a humidistat, and motor starting relays as shown by the block diagram in **Figure 2.** The quick disconnect and fused protection fulfill standard code and safety requirements. The fan and heater selector switches permit operation and management of the system in accordance with recommended procedures. Basically, the fans are initially set on manual operation and force natural air through the tobacco continuously for the first two or three weeks of curing. Heat is off unless turned on to hasten moisture removal from big turgid tobacco or to aid drying during a rainy, humid period. Heat operations are controlled manually or by a humidistat. The humidistat is in the top of the barn and is set at 65%. After about three weeks when moisture liberation has been reduced greatly, the time clock is set to operate the fans for only four to six hours daily to remove accumulated moisture.

BARN EVALUATION

Demonstration barns were built by two interested farmer-cooperators in 1967, through cooperative extension projects. Several others have been built since. The farmers have been quite pleased and satisfied with the operation and performance of their facilities. Based on sales price of the tobacco, curing results with the two-tier barn have been equivalent to or slightly better than those of conventional curing. In 1968 the average from 5 barns in 4 different counties was $74/cwt for 15,084 lb. compared with $72/cwt for 15,288 lb. from the same farms.

Desirable features of the two-tier barn and the associated tobacco housing methods have been a smaller crew size required to load the barn and a reduction in the total man-hours to house the tobacco. Two men can fill the barn, compared with three to five men required in conventional barns. Labor studies by Byers (1) have shown 10-12 man-hours are required per acre to load the two-tier barn compared with 20-25 man-hours per acre for conventional barns, thus a labor reduction in the tobacco housing operations of about 50 percent. Operating costs are $10-$15/A for electricity and 0-$50/A for gas with the majority of the farmers operating for less than $25/A per year for gas. Gas costs vary with weather conditions and management practices. However, in conventional curing, farmers will probably use more fuel during periods of bad curing weather than used in the two-tier barn because of poor efficiency in methods of application.

In 1969, one barn was instrumented for studying the environmental patterns. Dry-bulb and dew-point temperature sensors were placed at 20 points throughout the tobacco (see note on **Figure 1**) as it was loaded into the barn. These sensors were connected to automatic recording equipment which logged records at 4-hour intervals. The tobacco was loaded between 10 a.m. and noon on Sept. 4, 1969, and data recording started at 8 p.m. the same date.

Figure 3 shows the environmental performance of the barn for the first 5 days of the cure. In **Figure 3** the average of all 20 points within the tobacco mass are compared with the conditions outside the barn. During this time the fans operated continuously and the heater was turned on as shown in **Figure 3.** The average environmental conditions (over time) for the barn is about the same as for ambient conditions. However, the barn acts to reduce the extreme variations of the ambient conditions, as can be seen in **Figure** 3. This reduction in environmental extremes within the barn reduces the likelihood of undesirable irreversible chemical changes in the tobacco, thus offering a curing advantage.

The environmental conditions within the barn are very uniform (less than 2 degrees variation in temper- wind is not blowing. Under high radiation and wind ature) at night and during cloudy periods when the rates, much wider environmental gradients develop within the barn. **Figures 4-7** show the gradients which existed in the barn at 4 p.m. on the seventh day of the cure. The ambient conditions at the time the data were taken were: Bright sunshine, 84°F, 33.25% r.h. and a wind velocity of 5 mph out of the NNW, represent one of the most extreme conditions recorded

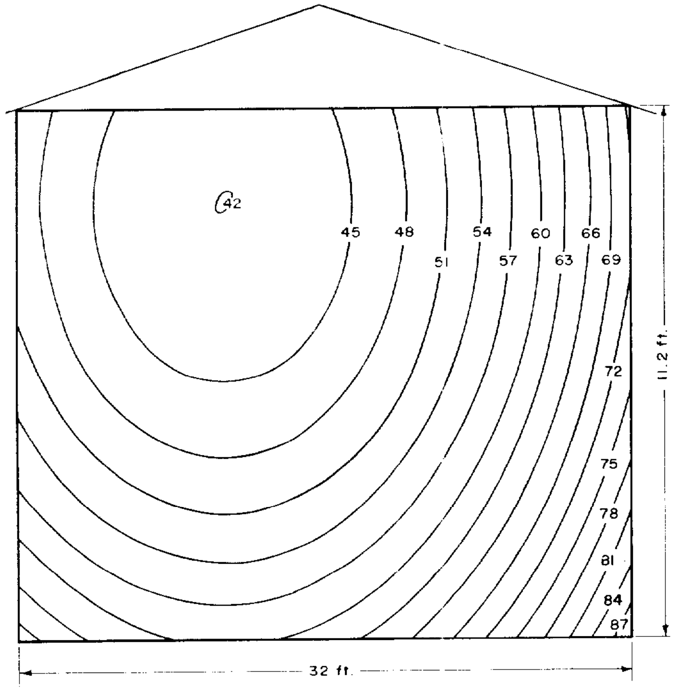

Figure 7. End sectional view of relative humidity profile in two-tier forced ventilation burley tobacco curing barn for ambient relative humidity of 33.25% and wind velocity of 5 mph.

during the study. These graphs were developed by first fitting the recorded data to regression polynomials and then using these polynomials to calculate values plotted in **Figures 4-7. Figures** 4 and 5 represent a side view vertical plan through the tobacco halfway between the fans and the sidewall of the barn (Section A-A as shown in **Figure** 8). **Figures 6** and **7** represent an end-view vertical plan through the tobacco located as indicated by Section B-B in **Figure 8.**

Temperature and relative humidity gradients indicated in **Figures** 4-7 are in the range of those reported by O'Bannon (8) for the lower part of conventional barns. Under high radiation conditions, O'Bannon (8) reported extremely high temperatures in the top of conventional barns. For an ambient temperature of 84°F and an 8 mph wind, he found temperatures as high as 91°F. Under similar conditions, the temperatures in the two-tier barn never exceeded ambient temperatures. In the two-tier barn these high temperatures are eliminated by the forced ventilation system taking in air from under the roof and distributing it throughout the tobacco. This also gives a little "free" heat energy for evaporating moisture from the tobacco.

SUMMARY

From investigations into burley tobacco curing methods at the Kentucky Agricultural Experiment Station have evolved consideration of and criteria for a new curing structure. The structure is a two-tier forced-ventilation curing system utilizing higher loading densities than conventional barns. High loading densities reduce the barn volume needed per acre and aids in uniform air distribution under the forced-air system. A basic pole-frame trussed-roof design was used to provide more versatility and adaptability in the use of the structure.

Electrical controls for the ventilation system give more managerial control over the curing process. Other features of the forced-ventilation system reduce the effects of ambient environmental extremes and reduce the environmental gradients within the curing tobacco. The two-tier design and higher loading densities reduce the labor crew size and the total labor required to house tobacco, in the new burley tobacco curing barn.

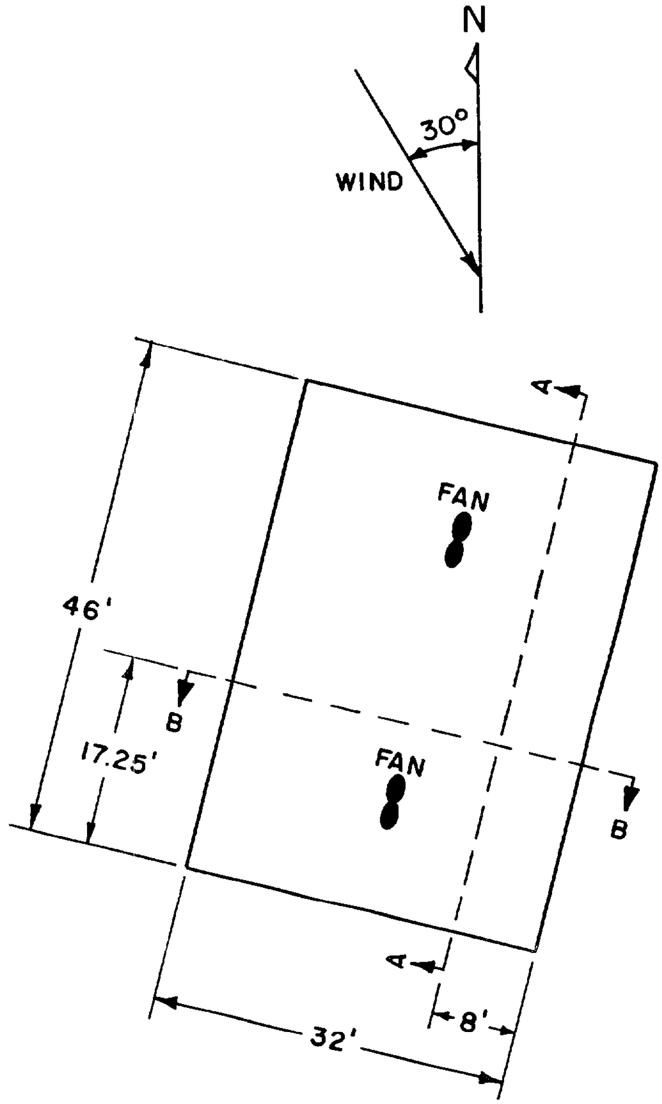

Figure 8. Plan view of two-tier forced ventilation burley tobacco curing barn showing fan locations, sectional view locations and ambient wind direction.

LITERATURE CITED

1. Byers, George G. Personal Communications. Unpublished file copy. University of Kentucky, Lexington, Kentucky, 1969.
2. Duncan, George A. and Joe M. Bunn. Forced Ventilation Curing Studies and a New Burley Barn Design. Paper presented at the Southeast Region of ASAE Meeting, Louisville, Kentucky; February 15-7, 1968.
3. Henson, W. H., Jr. (Ed.) 1961 Annual Research Report on Harvesting and Curing Burley Tobacco. Unpublished report. Department of Agricultural Engineering, University of Kentucky, Lexington, Kentucky, 40506; March, 1962.
4. Henson, W. H., Jr. (Ed.) 1962 Annual Research Report on Harvesting and Curing Burley Tobacco. Unpublished report. Department of Agricultural Engineering, University of Kentucky, Lexington, Kentucky 40506; March, 1963.
5. Henson, W. H., Jr. (Ed.) 1964 Annual Research Report on Harvesting and Curing Burley Tobacco. Unpublished report. Department of Agricultural Engineering, University of Kentucky, Lexington, Kentucky, 40506; March, 1965.
6. Henson, W. H., Jr. (Ed.) 1966 Annual Research Report on Harvesting and Curing Burley Tobacco. Unpublished report. Department of Agricultural Engineering, University of Kentucky, Lexington, Kentucky, 40506; March, 1967.
7. Henson, W. H., Jr., (Ed.) 1967 Annual Research Report on Harvesting and Curing Burley Tobacco. Unpublished report. Department of Agricultural Engineering, University of Kentucky, Lexington, Kentucky, 40506; March, 1968.
8. O'Bannon, Lester S. Distribution of Temperature and Relative Humidity Within a Burley Tobacco Barn. Kentucky Agricultural Experiment Station Bulletin 444. University of Kentucky, Lexington, Kentucky, 1943.
9. Parker, B. F. and G. M. White. Effectiveness of Jets Produced by Fan-Baffle Arrangement for Mixing and Distributing Ventilating Air. **Transactions on the ASAE 9(4)**:480-483, 488. 1966.