# ENGINEERING ECONOMY AND ENERGY CONSIDERATIONS

## ENVIRONMENTAL CONDITIONS FOR PLACING ASPHALTIC CONCRETE PAVEMENTS

RESEARCH REPORT 214-11

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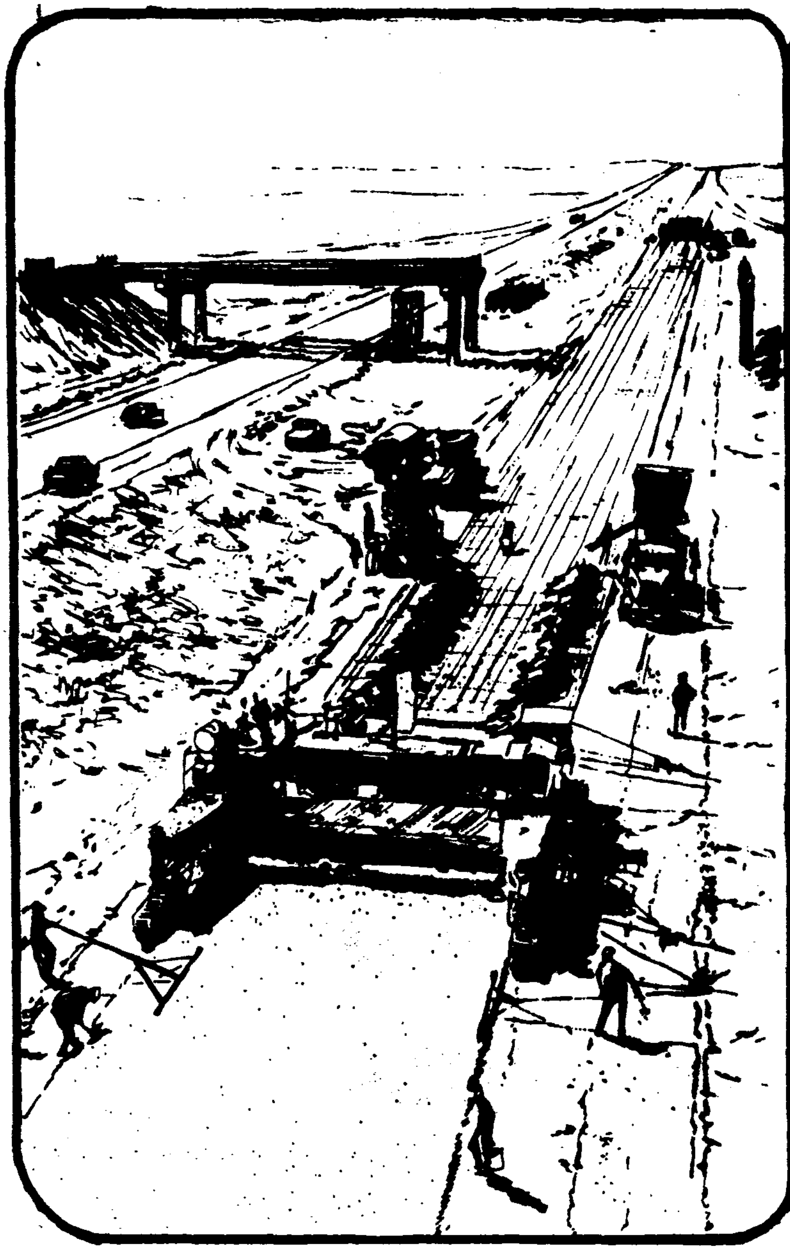

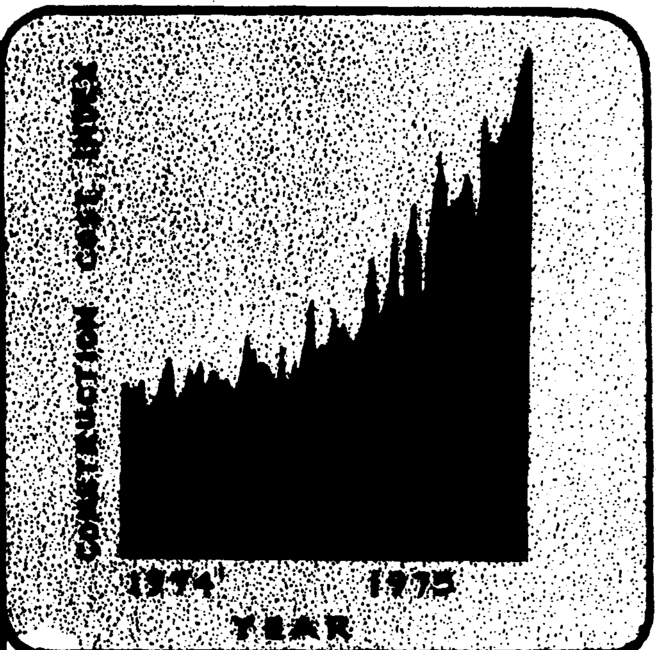

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"ENGINEERING, ECONOMY AND ENERGY
CONSIDERATIONS IN DESIGN,
CONSTRUCTION AND MATERIALS"

TEXAS STATE DEPARTMENT
OF HIGHWAYS
AND PUBLIC TRANSPORTATION
AND
TEXAS TRANSPORTATION INSTITUTE
TEXAS A&M UNIVERSITY

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# ENVIRONMENTAL CONDITIONS FOR PLACING ASPHALT CONCRETE

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## Introduction

The importance of proper compaction of asphalt concrete pavements has been recognized for many years. Engineers have shown that pavement stability, durability, tensile strength, fatigue resistance, stiffness, flexibility and pavement performance are controlled to a certain degree by the density of the asphalt concrete.

To insure adequate compaction, agencies specify initial in-place density and/or paving temperature limitations. The paving temperature limitations or cessation requirements are based on air temperature (except for a very few agencies that use base temperature). Paving is permitted when the air temperature is a certain value and not remitted when the temperature is below a certain value. These requirements are based on historical experience and are intended to regulate construction so that paving is permitted only when conditions are favorable for obtaining a satisfactory density.

Initial in-place density requirements are often based on standard laboratory density. For example, when the State Department of Highways and Public Transportation specifies in-place density for surface course mixtures, it is usually relative to the density obtained in the laboratory utilizing a standard gyratory compaction method. A common density range for field cores is from 95 to 100 percent of the density achieved in the laboratory. The laboratory density presently specified by Texas is from 95 to 99 percent of theoretical maximum density with 97 percent suggested as optimum (1). The specification ranges indicate an air void content of from 1 to 5 percent in the laboratory mixtures and from 1 to 10 percent air voids allowable for in-place density. Desirable in-place air voids are 3 to 5 percent.

Test results from 15 test sections placed in Texas from 1965 to 1967 indicate that initial air void contents of from 8 to 12 percent were common (2). During two years of traffic these pavements would decrease in air void content from about 3 to 6 percent. Over half of the pavements had an initial air void content in excess of 10 percent. Results of this study indicate the importance of obtaining density during construction as traffic will densify a pavement only a limited amount in service under most conditions.

Methods have recently been developed to allow the engineer to determine under what environmental conditions he is likely to successfully place asphalt concrete and achieve the desirable in-place density for a given mat or thickness (3, 4, 5, 6, 7, 8, 9). These methods will be utilized to explore the validity of the current Texas cessation limits given below.

"The prime coat, tack coat or the asphaltic mixtures, when placed with a spreading and finishing machine, shall not be placed when the air temperature is below 50°F and falling; but it may be placed when the air temperature is above 40°F and rising". This limitation according to the data presented below prohibits the placement of asphalt concrete several days a year in the southern part of the state and for weeks at a time in the northern parts of the state when satisfactory densification could probably be achieved. Thus a better definition of when asphalt concrete can be placed will result in an extended construction season allowing better equipment utilization and perhaps a reduction in cost of placement of asphalt concrete mixtures.

On the other hand, the current Texas cessation requirement allows construction of thin asphalt concrete mats under conditions when satisfactory densification cannot be achieved. Thus, higher maintenance and/or rehabilitation costs will result. Details illustrating the limitations of the present Texas cessation requirements are presented below.

## Background Information

Corlew and Dickson (3, 4, 5) were among the first to utilize heat transfer models to predict cool-down rates for asphalt concrete mixtures. Wind velocity, initial base temperature, solar radiation, air temperature, asphalt concrete mixture temperature, mat or lift thickness and thermal properties of the base and asphalt concrete mixture were considered in these solutions. Corlew and Dickson's work was utilized by Foster (6) to establish cessation requirements for constructing asphalt concrete pavements. Based on Foster's work, Maupin (7) has developed a specification which is utilized in Virginia to determine cold weather paving limitations. Factors considered to establish this limitation include; mat temperature, time available for compaction and base temperature.

Dempsey (8, 9) has extended the work of Corlew and Dickson, Foster and others such that the following factors can be considered as inputs and variables in determining the time available to compact asphalt concrete.

1. Time of day and day of year,
2. Percent sunshine or percent of sky not covered by clouds,
3. Average wind velocity,
4. Ambient air temperature,
5. Temperature of asphalt concrete,
6. Temperature difference between asphalt concrete and air,
7. Temperature of surface upon which hot-mix is to be placed, and
8. Thickness of mat to be placed.

Results of the above mentioned research can be utilized to illustrate the relative effect of the above mentioned factors on the time available for compacting asphalt concrete. Figures 1, 2, 3 and 4 illustrate the effect of mixture temperature, mat thickness, wind velocity and surface temperature on the time available for compaction. The time available for compaction is defined as the increment of time between placing of the mat and the cooling of the mat to 175°F. Figure 5 was prepared using the method developed by Dempsey and Tegeler (9) and utilizing the same conditions as Foster (6) and Dickson and Corlew (4) (See Table 1). From these data it is apparent that the major factors controlling the time available to achieve adequate compaction are as follows;

1. Base temperature,
2. Mat temperature or temperature of the asphalt concrete mat at the time of placement, and
3. Mat thickness.

Air temperature, percent sunshine and solar radiation are included to some degree in base temperature.

Additional calculations utilizing Demsey's method assuming the following illustrates the difficulty of using only air temperatures when establishing cessation requirements.

1. 8:00 am on January 20,
2. 40 percent sunshine,
3. 15 mph wind velocity,
4. Air temperatures of 10, 20, 35 and 40,
5. Temperature of asphalt concrete 300°F,
6. Base temperatures of 20, 30, 40 and 50,
7. Mat thickness of 1, 2 and 3 inches.

Results of these calculations are shown in Tables 2, 3 and 4. From the various mat thicknesses and base temperatures it is apparent that at least 15 minutes of compaction time is available for 2-and 3-inch mats under the worst temperature conditions. However, even under the more desirable conditions, there is not enough compaction time available to produce the desired density in the 1-inch mat.

Figure 1
Mix Temperature Effect
(after Foster) (6)

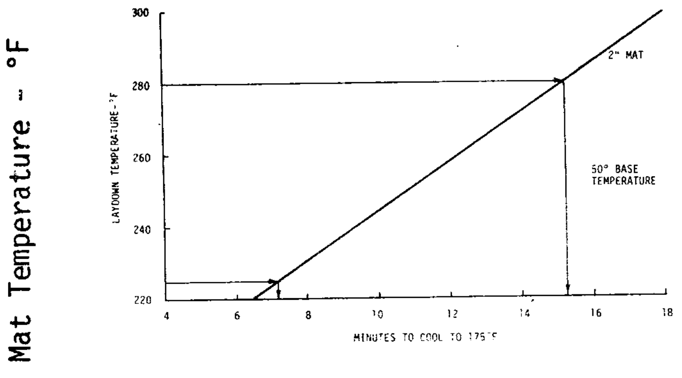


Figure 2
Mat Thickness
(after Foster) (6)

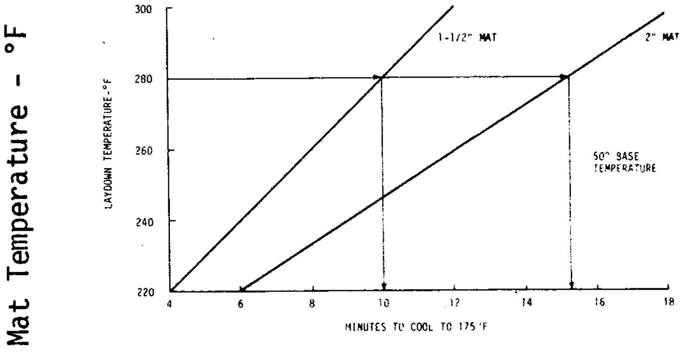


Figure 3
Wind Effect
(after Tegeler and Dempsey) (4) (8)

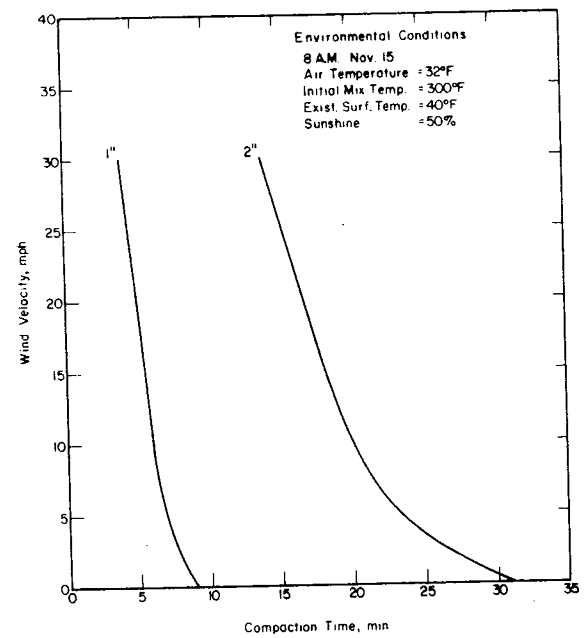


Figure 4
Surface Temperature Effect
(after Tegeler and Dempsey) (4) (8)

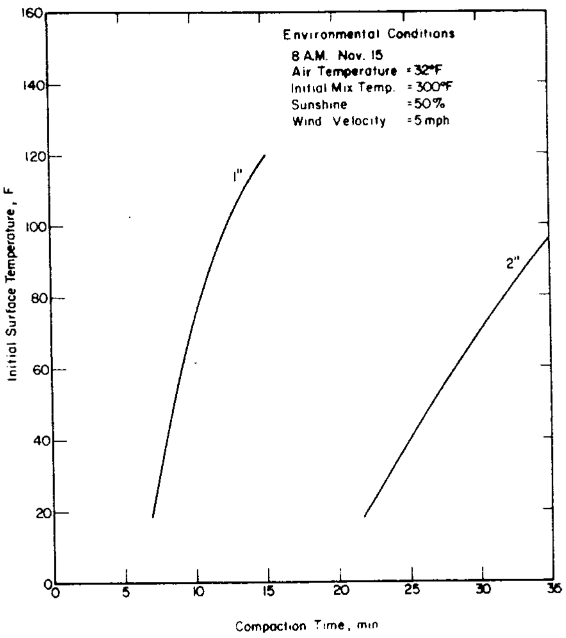


Figure 5

Effects of Surface Temperature

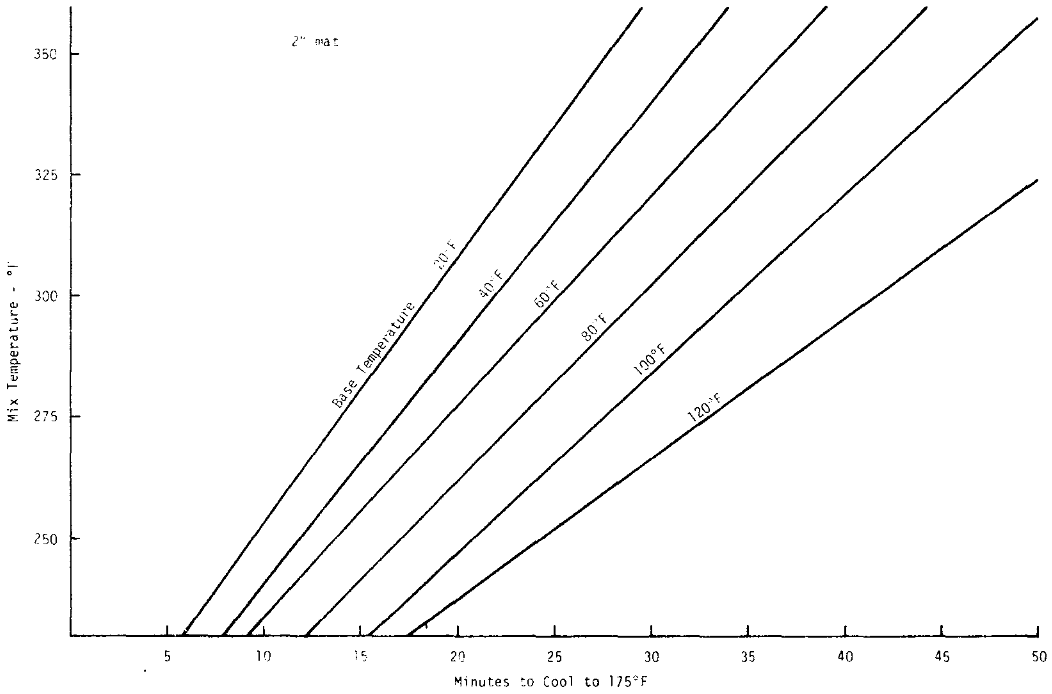


Table 1

| Sunshine | Solar Radiation BTU/FT$^2$/hr | Surface Temperature °F | Air Temperature °F |
|---|---|---|---|
| 50% | 50 | 20 | 20 |
| 50% | 50 | 40 | 40 |
| 50% | 100 | 60 | 50 |
| 50% | 100 | 80 | 70 |
| 50% | 200 | 100 | 80 |
| 50% | 200 | 120 | 100 |

### Table 2
### Compaction Time (Minutes) for 3" Mat Thickness

| Surface Temperature °F | Air Temperature °F | | | |
|---|---|---|---|---|
| | 40 | 30 | 20 | 10 |
| 50 | 34 | 33 | 32 | 31 |
| 40 | 32 | 31 | 30.5 | 30 |
| 30 | 30 | 29 | 28 | 27.5 |
| 20 | 28 | 27 | 26.5 | 26 |

### Table 3
### Compaction Time (Minutes) for 2" Mat Thickness

| Surface Temperature °F | Air Temperature °F | | | |
|---|---|---|---|---|
| | 40 | 30 | 20 | 10 |
| 50 | 21.5 | 21 | 20.5 | 20 |
| 40 | 20 | 19.5 | 19 | 19 |
| 30 | 18.5 | 17 | 17 | 17 |
| 20 | 17 | 16.5 | 16 | 16 |

### Table 4
### Compaction Time (Minutes) for 1" Mat Thickness

| Surface Temperature °F | Air Temperature °F | | | |
|---|---|---|---|---|
| | 40 | 30 | 20 | 10 |
| 50 | 7 | 6.75 | 6.6 | 6.6 |
| 40 | 6.25 | 6.25 | 6 | 6 |
| 30 | 5.75 | 5.65 | 5.5 | 5 |
| 20 | 5.20 | 5.20 | 5 | 5 |

Fifteen and eight minute compaction times were specifically referred to above as these are the times selected by the National Asphalt Pavement Association Quality Improvement Committee as being desirable for thick lifts and thin lifts respectively (6). Specific delineation between thick and thin lifts may, however, not be needed because the 8-minute time could be used for any thickness of lift if rollers were available that could accomplish the required compaction in 8 minutes. The 8-minute and 15-minute available compaction time has been adopted by Virginia (7) to imply that two rollers must be available for breakdown rolling to obtain desirable compaction in 8 minutes and one roller for the 15-minute criteria.

## Establishing Cessation Requirements

From the above discussion it appears as if air temperature is not sufficient by itself to establish cessation requirements. A more logical requirement would be to stop placing asphalt concrete mixtures when conditions are such that the contractor will not have a "reasonable time" to compact the pavement before it cools such that it cannot be densified. The discussion above describes methods that can be utilized to establish these conditions and illustrates those factors that assume significance in the calculations.

Utilizing Figure 5 as a basis, Figures 6 and 7 have been prepared as described by Foster (6) to establish cessation requirements. These figures represent a go-no go combination of mix and base temperatures for 8-minute and 15-minute compaction times. If the combination of base and mix temperatures are above the line the asphalt concrete may be placed allowing a minimum rolling time. Included in Figures 6 and 7 are the compaction curves for one-and two-inch mats. Under the conditions utilized for this calculation 3-inch mats have cooling times in excess of 15 minutes.

Figure 6

Requirements for 8-Minute Rolling Time

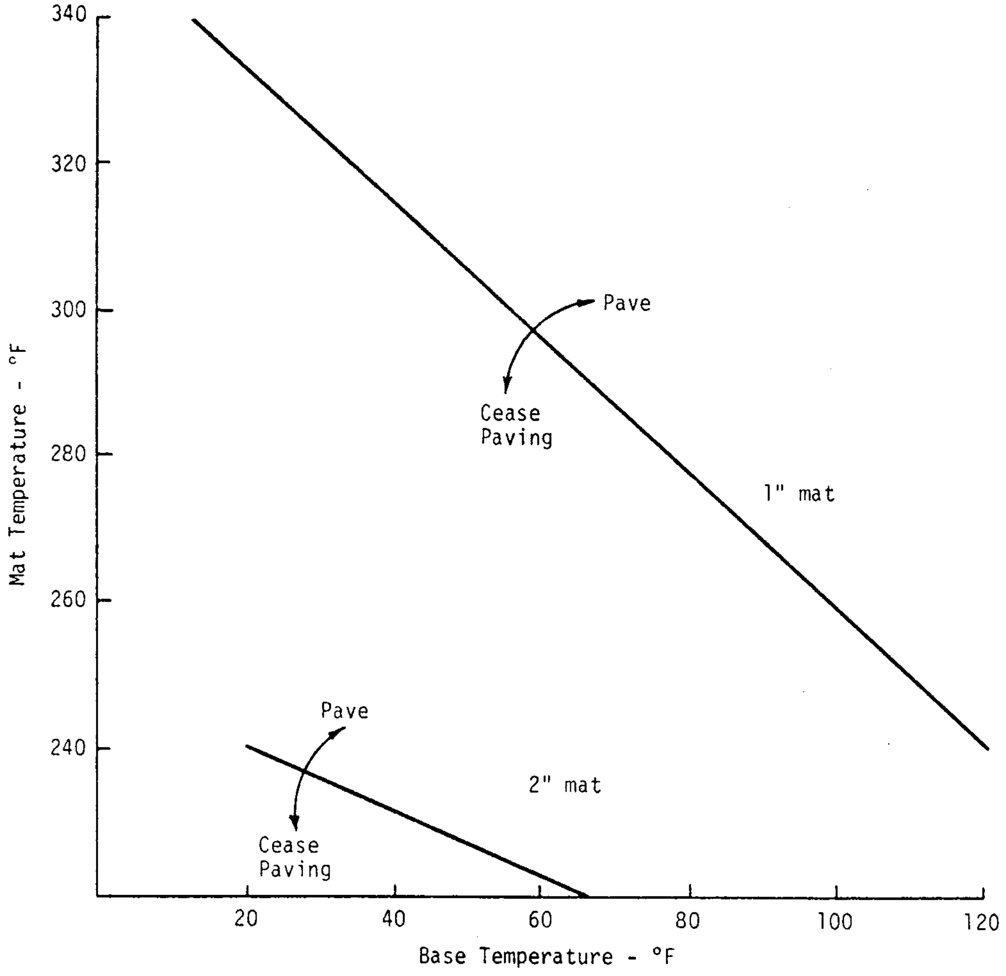
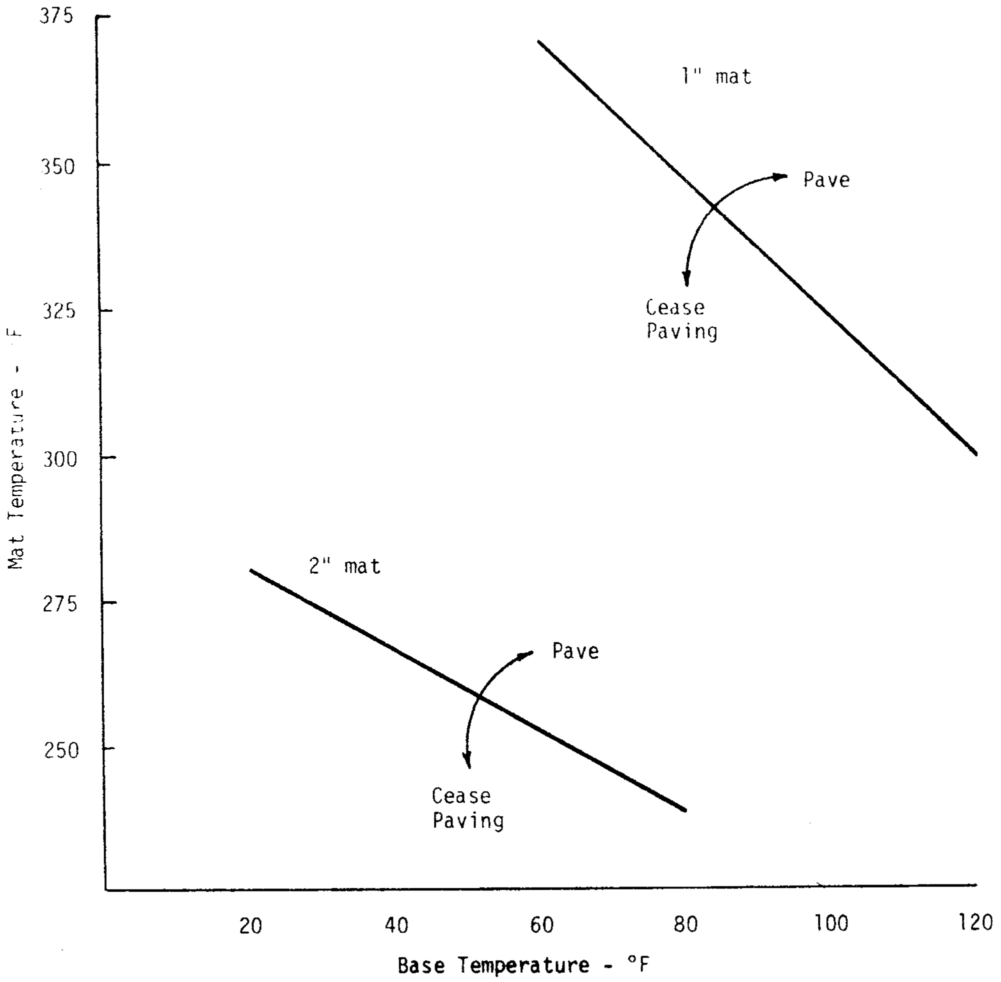


Figure 7

Requirements for 15-Minute Rolling Time



A second method of establishing cessation requirements is by use of a nomograph solution such as that utilized in Virginia and shown in Figure 8. Mat and base temperature are utilized to determine available compaction time.

A third method available to establish cessation requirements is that proposed by Dempsey (8, 9).

This procedure developed for Illinois latitude is defined in detail in the Appendix of this report. After discussions with Dempsey as to the effects of changing the latitude from 40° in Illinois to say 31° in Texas, it was determined that only Section 3 of Figure 1 in the Appendix would change. This graph is of solar radiation by time of day and day of year. Extraterrestrial radiation is higher at lower latitudes; therefore, more heat would be radiated into the hot mix on any day at lower latitudes, if cloud cover is equal. This additional heat input would provide a slight addition to compaction time. Table 5 presents a comparison of extraterrestrial radiation between latitudes 40°N and 32° 27'N.

Table 5

Solar Radiation at Noon (BTU/hr-$FT^2$)

| Latitude | Jan 1 | Jan 2 | Jan 3 | Jan 4 | Jan 5 |
|---|---|---|---|---|---|
| 40°N | 201.4 | 202.5 | 203.6 | 204.4 | 205.1 |
| 32° 27'N | 238.6 | 239.1 | 239.7 | 240.3 | 240.9 |

The Dempsey method allows for a wide range of factors to be included by use of his nomographs and charts and does not necessitate the assumption for solar radiation, air temperature and wind velocity utilized to establish Figures 5, 6 and 7.

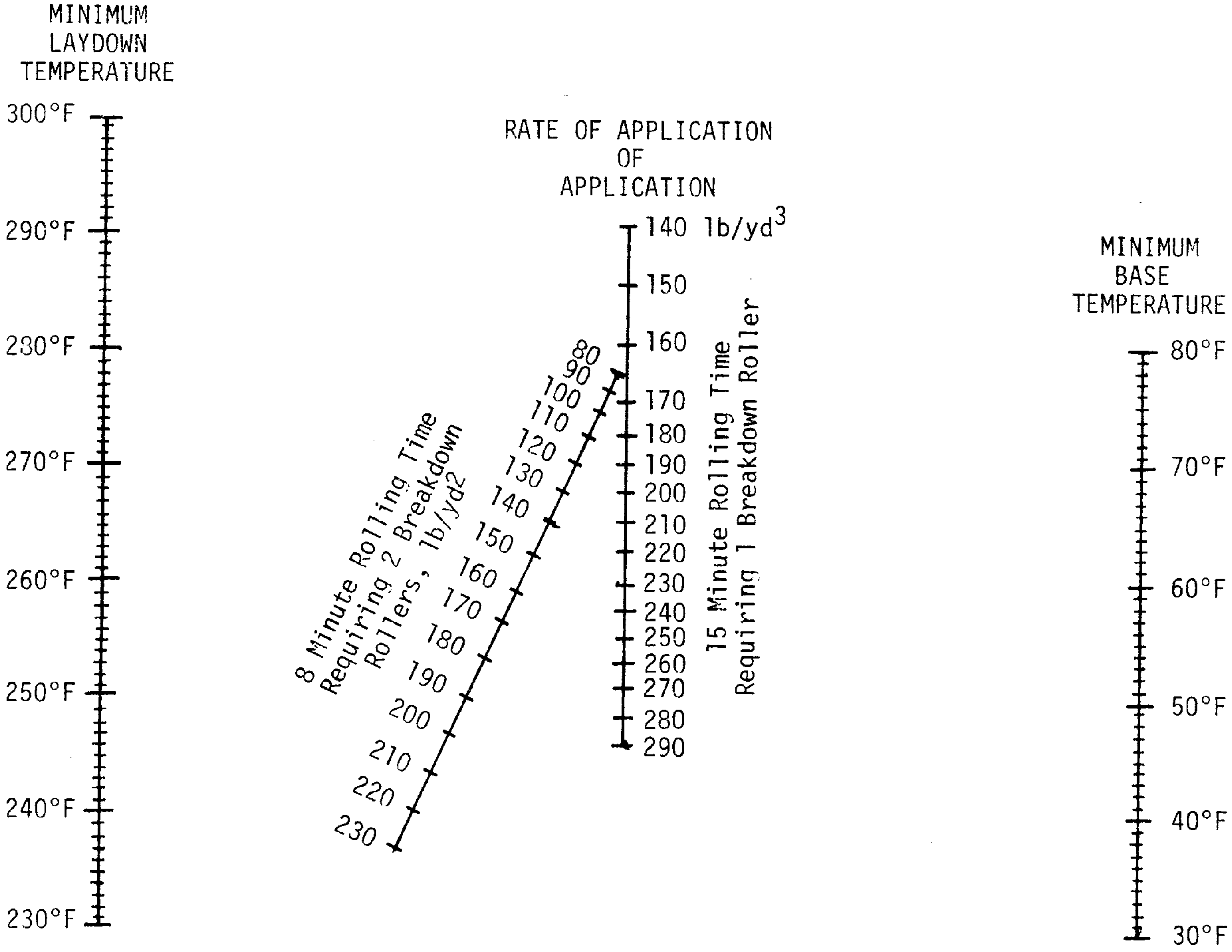


Figure 8

Cold Weather Paving Limitations

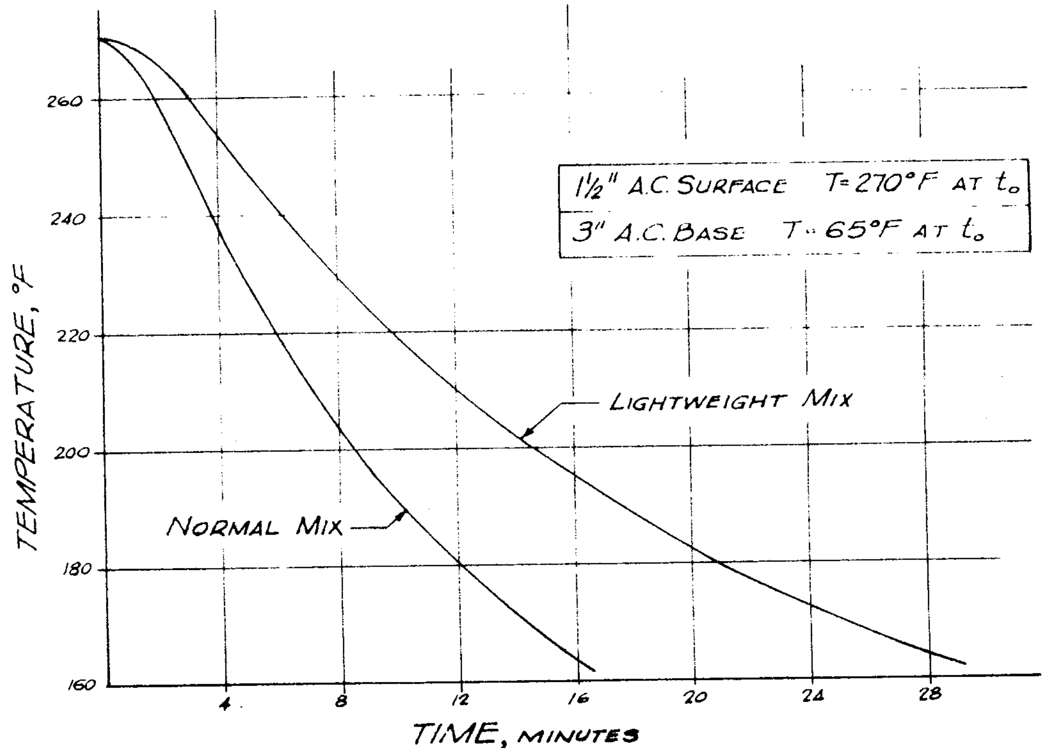
(After Maupin) (7)

Lightweight Aggregate Mix Consideration

Due to the limited availability of polish resistant aggregate, manufactured lightweight aggregate has been increasingly utilized. The characteristics of lightweight aggregates differ from natural, dense aggregates in water absorption capacity, water absorption rate, and thermal properties (10). Figure 9, from Gallaway, illustrates the difference in cooling curves for lightweight and normal aggregates under the same conditions.

Figure 9

Cooling Curves-Normal & Lightweight Mixes



Gallaway utilized the Corlew and Dickson (3) computer program and developed cooling curves for lightweight aggregate mixes. The results are summarized in Figure 10.

Thus far, the cooling curves presented for both normal and manufactured aggregates have assumed that the mix is dry. Lightweight aggregate has a higher moisture capacity and a slower rate of removal--as discussed by Gallaway (10). Figures 10 through 14 present Gallaway's findings on the effects of moisture on compaction time--assuming 175°F a cessation requirement.

In comparing lightweight and normal mixes, the moisture content of the lightweight mix will cause a faster rate of cooling than a normal mix. This is countered by the insulation properties of lightweight mixes. As a general assumption--if a lightweight mix is used and the moisture content is about .75%, the cooling curves of a normal aggregate present an approximation for the cooling curves of a lightweight aggregate mixture.

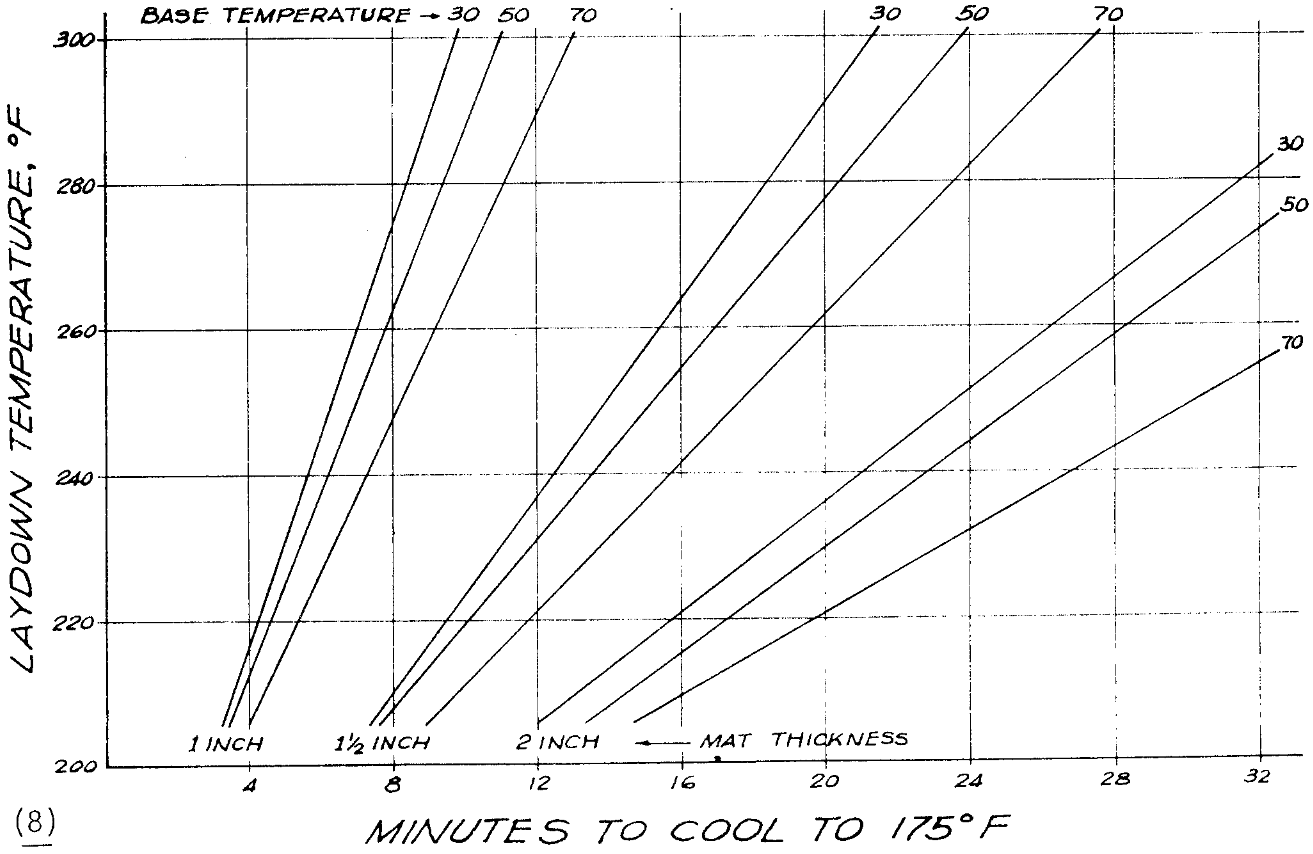
## Conclusion

The importance of proper compaction of asphalt concrete pavements has been recognized for many years. Engineers have shown that pavement stability, durability, tensile strength, fatigue resistance, stiffness, flexibility and pavement performance are controlled to a certain degree by the density of the asphalt concrete.

To insure adequate compaction, agencies specify initial "in-place" density and/or paving temperature limitations cessation limits. The paving temperature limitations or cessation requirements are based on air temperature (except for a very few agencies that use base temperature). Paving is permitted when the air temperature is above a certain value and stopped when the temperature is below a certain value. These requirements are based on historical experience and are intended to regulate construction so that paving is permitted only when conditions are favorable for obtaining a satisfactory density. In-place density requirements are often based on a percentage standard laboratory compaction density.

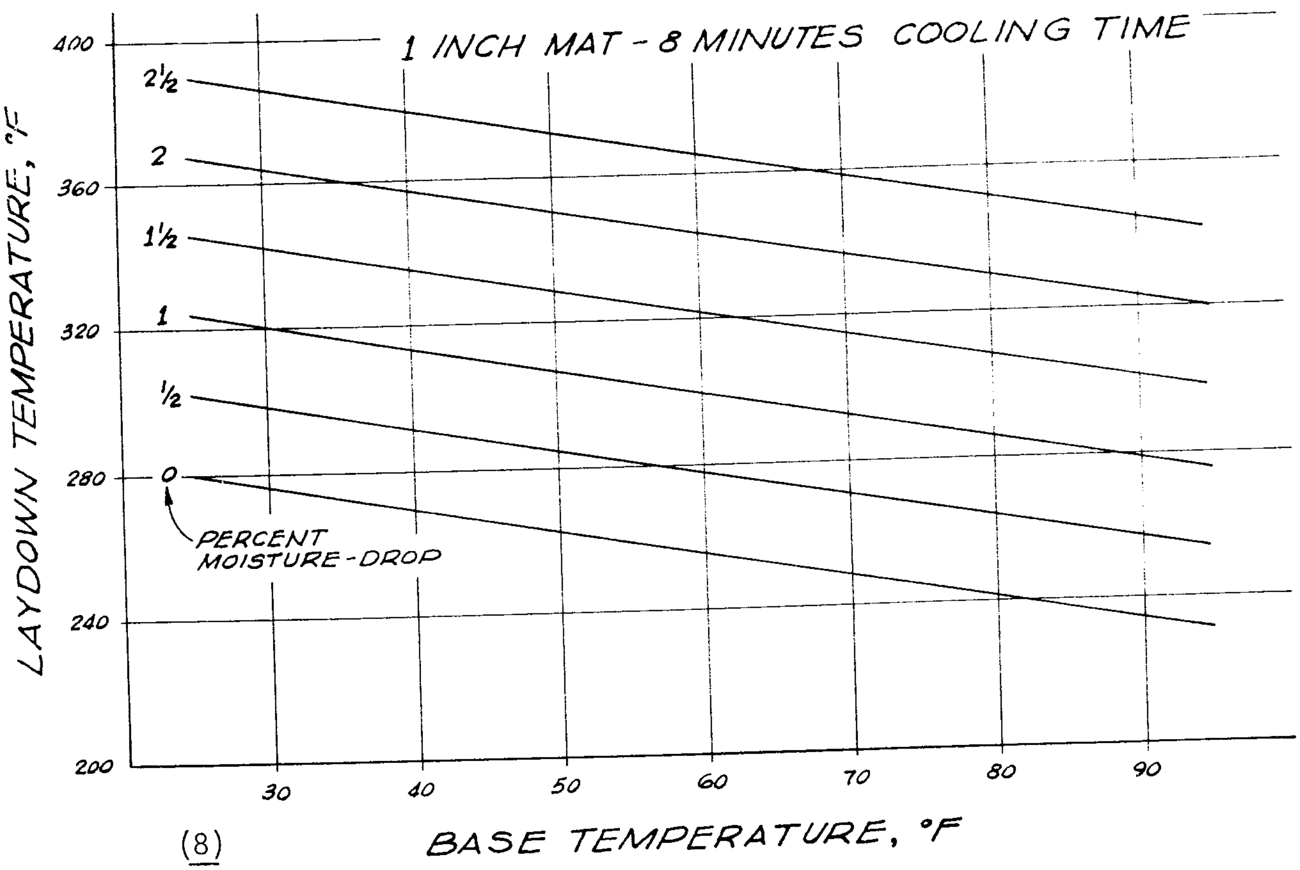
Figure 10

Effect of Base Temperature on Cooling



(8)

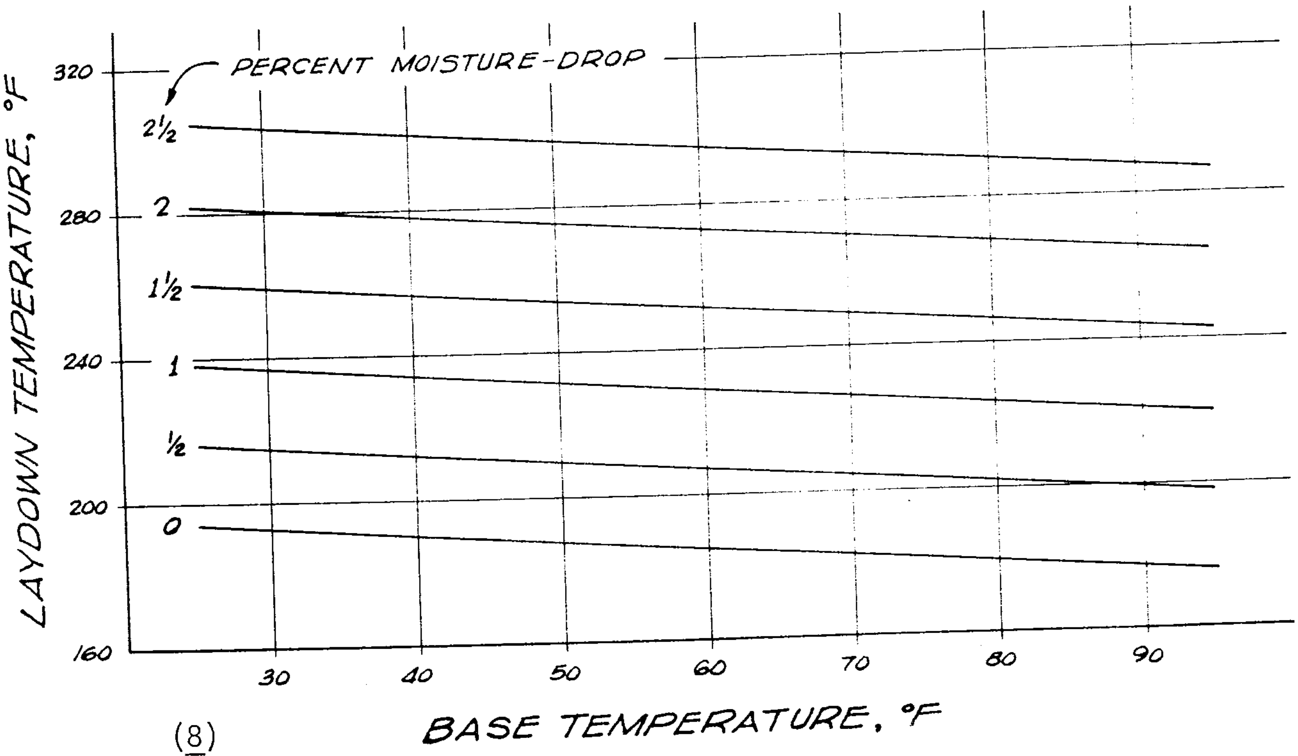
Figure 11
Cessation Requirements



(8)

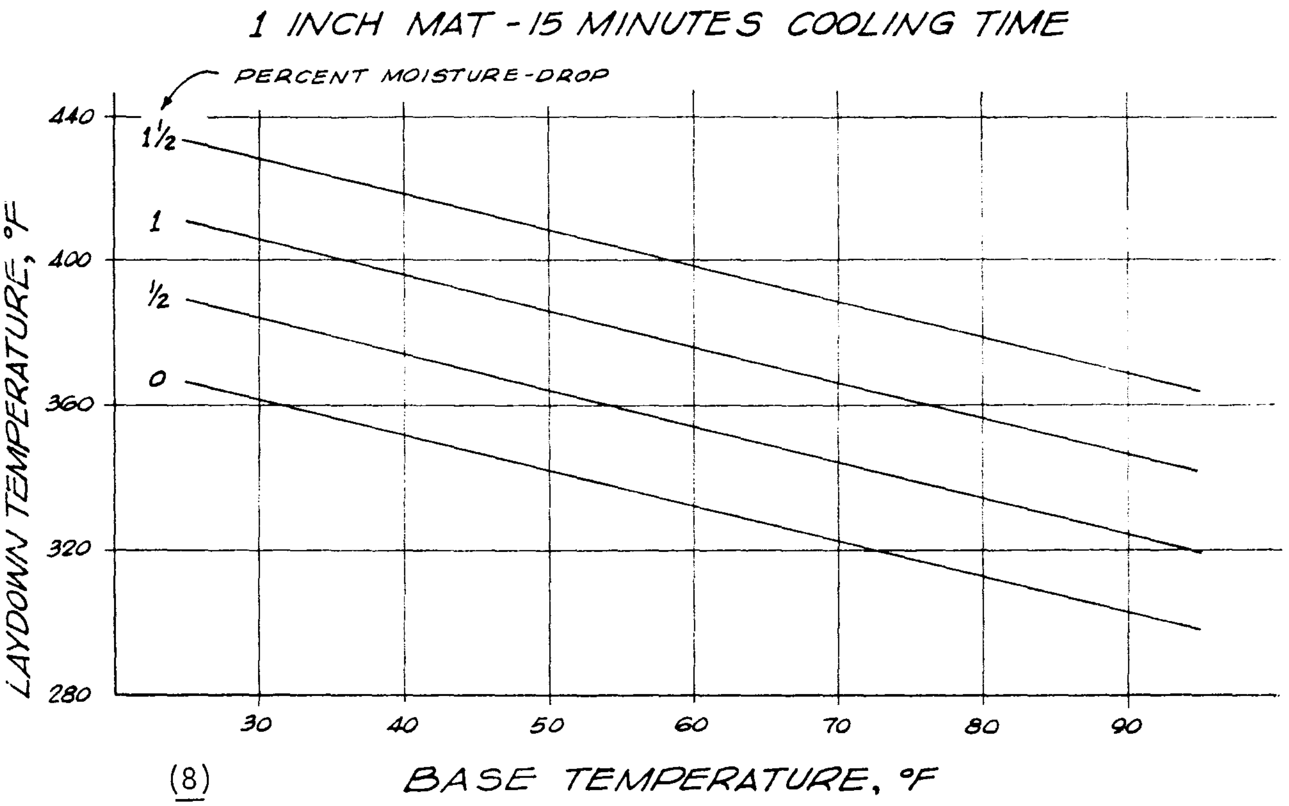
Figure 12
Cessation Requirements

2 INCH MAT - 8 MINUTES COOLING TIME



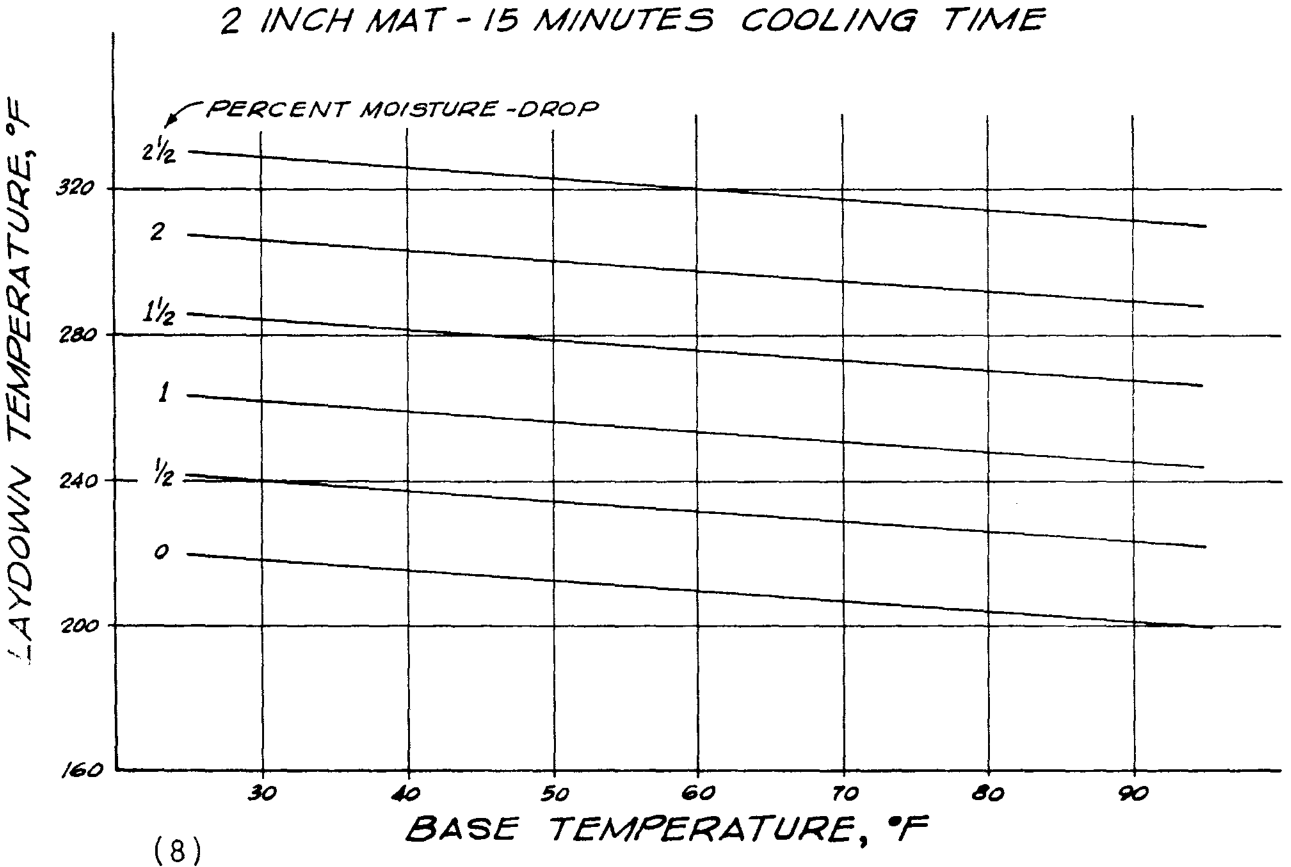
(8)

Figure 13
Cessation Requirements


1 INCH MAT - 15 MINUTES COOLING TIME

(8)

Figure 14
Cessation Requirements


2 INCH MAT - 15 MINUTES COOLING TIME

(8)

This paper describes procedures that can be utilized to explore the validity of cessation requirements based on air temperature only and illustrates that existing requirements as currently practiced in Texas unduly restrict the placement of thick lifts of asphalt concrete and are not sufficiently restrictive for thin lifts of asphalt concrete. Utilizing information presented in this report as a basis, it may be possible to extend the construction season if thick mats of asphalt concrete are to be placed. Extension of the construction season would allow a greater utilization of asphalt concrete related construction equipment and thus offer a potential cost savings. Additionally, construction of thin mats would be prohibited when insufficient compaction time was available and thus lower maintenance and rehabilitation costs would be expected during the life of the facility.

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10. Gallaway, B.M. Construction Guides for Placing Lightweight Hot-Mix Under Inclement Weather Conditions, Featherlite Corporation.

# APPENDIX

## PROCEDURE FOR DETERMINING COMPACTION TIME FOR HOT-MIX BITUMINOUS CONCRETE

The detailed procedure for utilizing the Climatic Input Chart, Figure 1, and the accompanying Compaction Time Curves, Figures 2 through 25, to determine available compaction time for hot-mix bituminous concrete is as follows:

1. Obtain the climatic data and pavement data listed below.
    a. Note the day of the year and the time of day.
    b. Percentage of sunshine or sky not covered with clouds (sunshine, %).
    c. Average wind velocity (mph).
    d. Temperature of air in degrees Fahrenheit ($T_{air}$, F).
    e. Temperature of the hot-mix bituminous concrete immediately before entering spreader in degrees Fahrenheit ($T_{mix}$, F).
    f. The difference between the temperature of the hot-mix bituminous concrete and the temperature of the air in degrees Fahrenheit ($\Delta T = T_{mix} - T_{air}$, F).
    g. Temperature of the existing surface upon which the hot-mix bituminous concrete will be placed in degrees Fahrenheit ($T_{surf}$, F).
    h. Thickness of the bituminous concrete lift to be placed (in.).
    i. Note the type of pavement system that is to be covered with the hot-mix bituminous concrete lift.
2. Enter graph 1 of the Climatic Input Chart, Figure 1, with the percentage of sunshine and draw a line parallel to line 1 until it intersects the appropriate $T_{mix}$ line.

3. Draw a line parallel to line 2 and project it entirely through graph 2.
4. Enter graph 3 with the day of the year and extend a line parallel to line 3 until it intersects the time of day.
5. Extend a line parallel to line 4 from the point located in step 4 until it intersects the line representing the percentage of sunshine in graph 4.
6. Draw a line from the point located in step 5 parallel to line 5 until it intersects the line in graph 2 which was produced in step 3.
7. Draw a line parallel to line 6 and extend it entirely across graph 5.
8. Enter graph 6 with the wind velocity and draw a line parallel to line 7 until it intersects the specified temperature difference, $\Delta T$, curve.
9. Draw a line parallel to line 8 from the point located in step 8 until it intersects the line from step 7 in graph 5.
10. Draw a line from the point located in step 9 parallel to line 9 to determine the heat loss factor, Q, in graph 7.
11. From the compaction time curves, Figures 2 through 25, select the figure which represents the pavement system and bituminous mixture temperature for which compaction time is to be determined.
12. Enter the x-axis with the heat loss factor, Q, determined in step 10 and extend a line parallel to the y-axis until it intersects the appropriate surface temperature curve, $T_{surf}$.

13. Draw a line from the point located in step 12 parallel to the x-axis to determine the available compaction time for the climatic conditions and pavement system specified.

The available compaction time is the time in which rolling must be completed in order to get sufficient density. The time begins at the instant the hot-mix is placed on the surface and ends when the mix has cooled to 175° F.

Note: Graph 3 is applicable only for a latitude of 40 degrees. However, a latitudinal difference of a few degrees would probably have very little effect on the available compaction time.

Examples

Two examples are presented below to demonstrate the use of the procedure outlined above. The initial conditions will be assumed as follows:

1. January 20
2. 40% sunshine
3. 8:00 a.m.
4. $T_{mix} = 300°F$
5. $T_{air} = 40°F$ and rising
6. $T_{surface} = 40°F$
7. Wind velocity 15 mph
8. Mat thickness = 3 in.

Using Figure 1, the heat loss factor is first determined and in this case is 1450 BTU/hr-FT$^2$. Using the appropriate figure (Figure 14) for mix temperature and mat thickness, the compaction time is found to be 32 minutes.

If the air temperature is assumed to be 20°F and the surface temperature is also 20°F, and all other conditions are the same as in the first example, the heat loss factor is determined to be 1500 BTU/hr-FT$^2$. Again, using Figure 14 and a surface temperature of 20°F the compaction time is found to be 27 minutes.

Additional examples were developed for mat thicknesses of 3 inches, 2 inches, and 1 inch, and the results are given in Tables 2, 3, and 4 on page seven in this report.

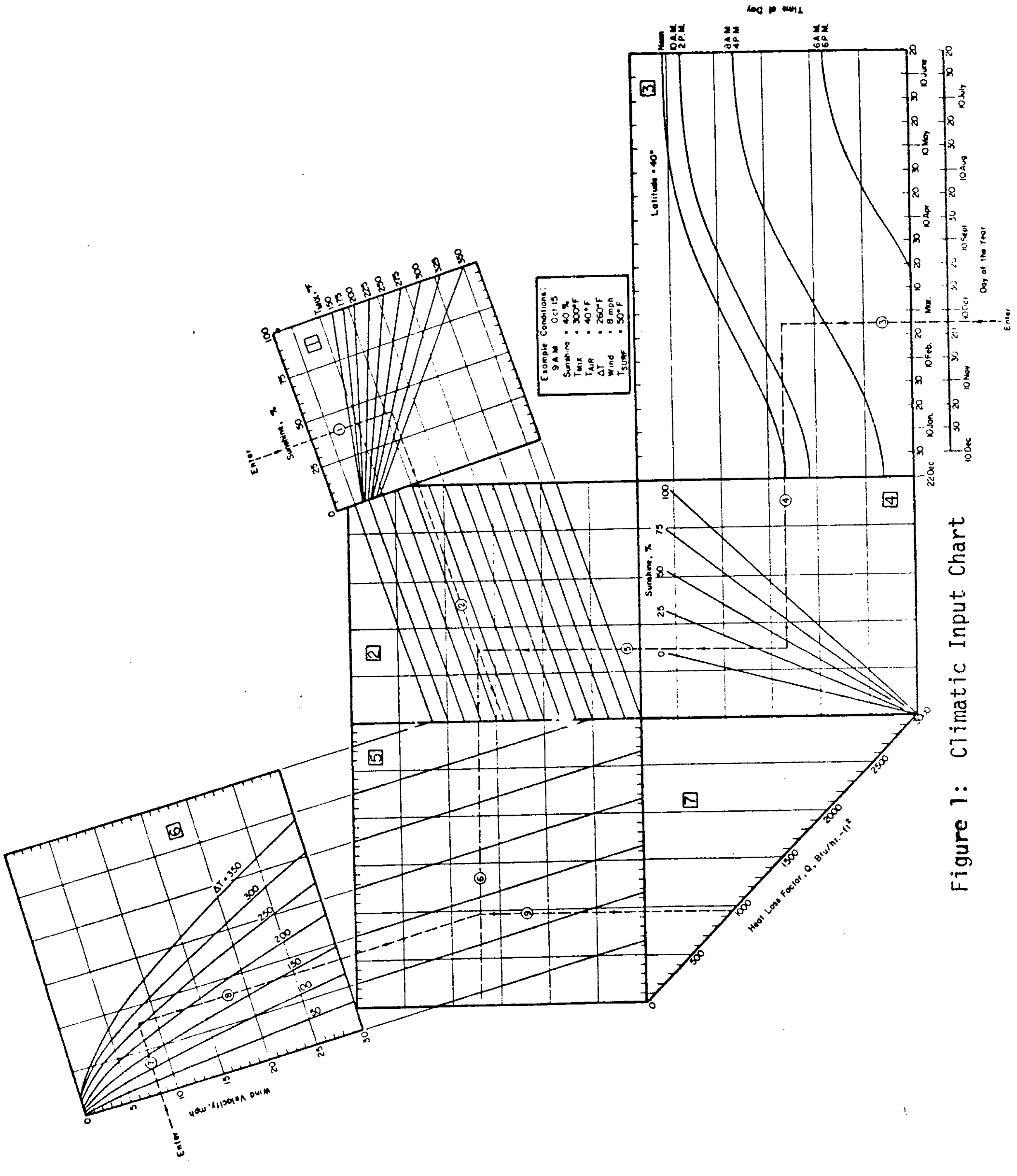

Figure 1: Climatic Input Chart

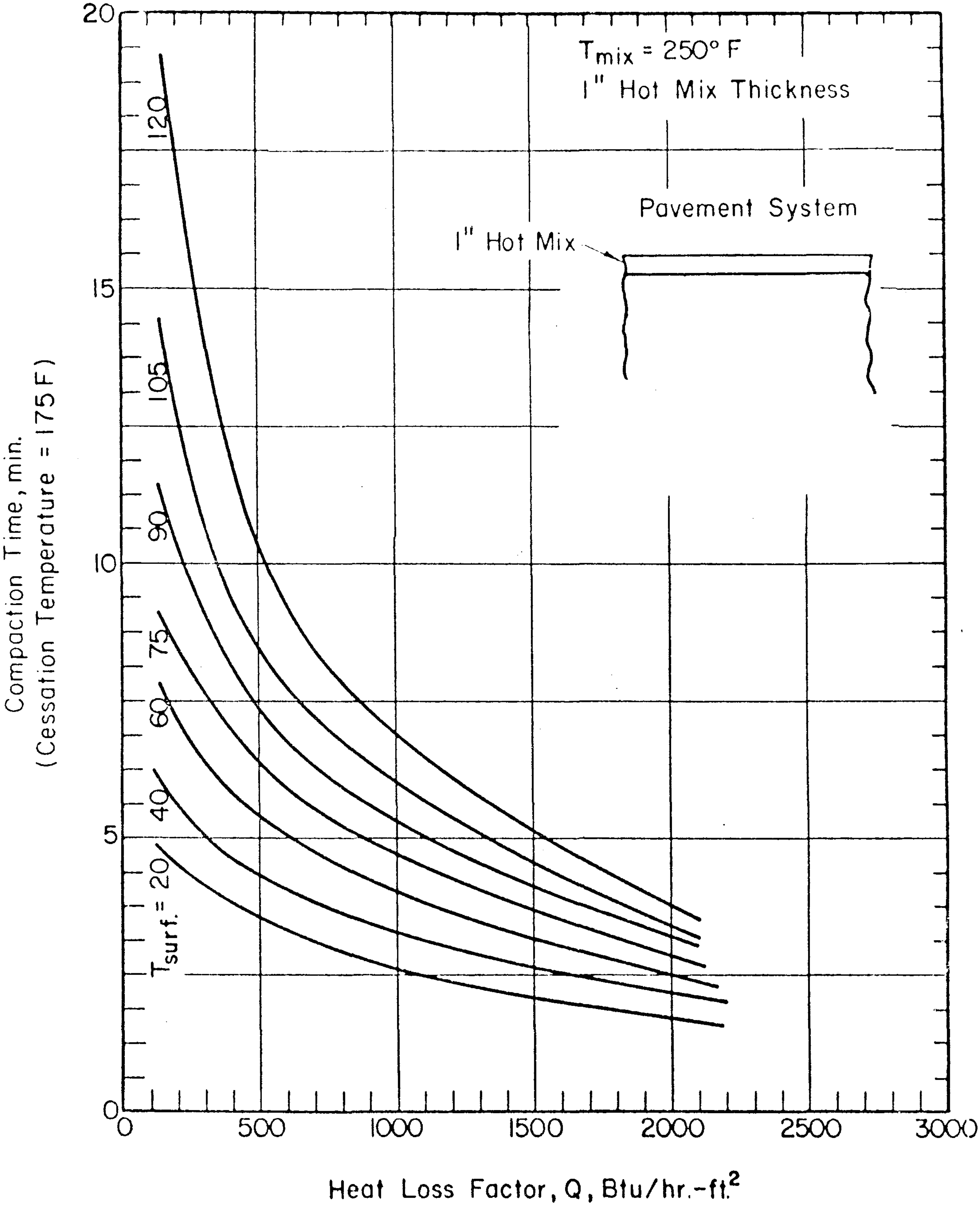

Figure 2: Compaction Time Curves

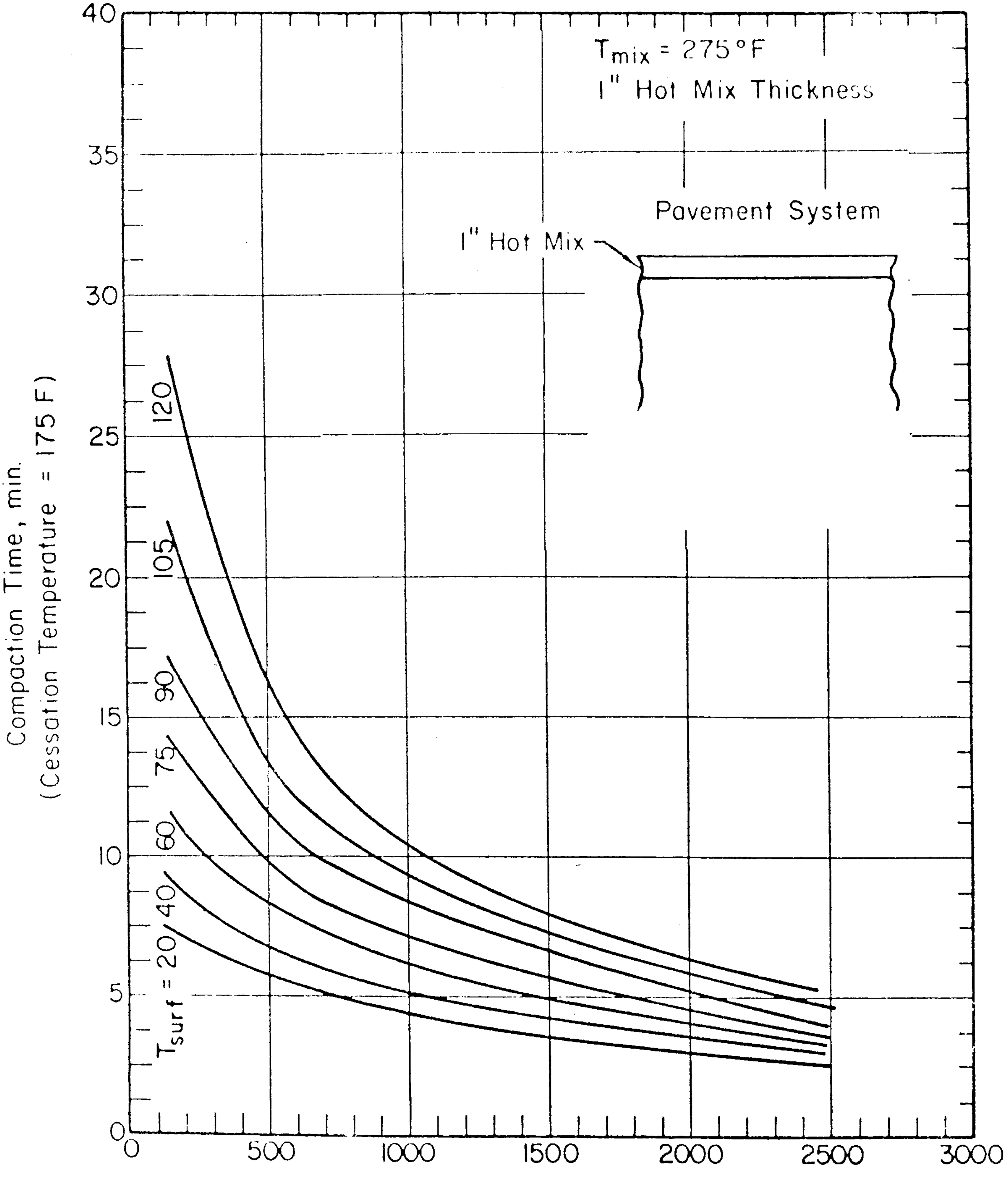

Figure 3: Compaction Time Curves

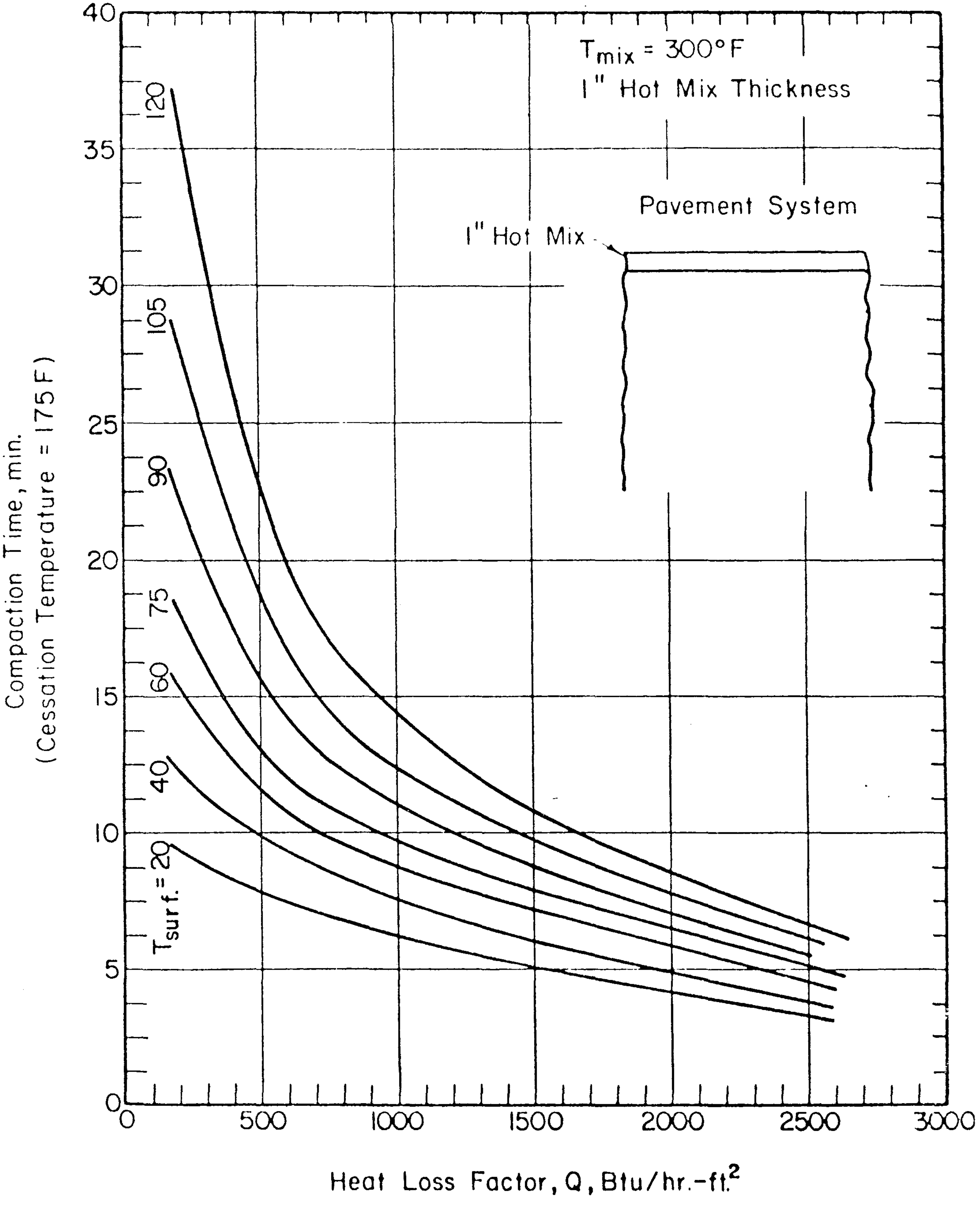

Figure 4: Compaction Time Curves

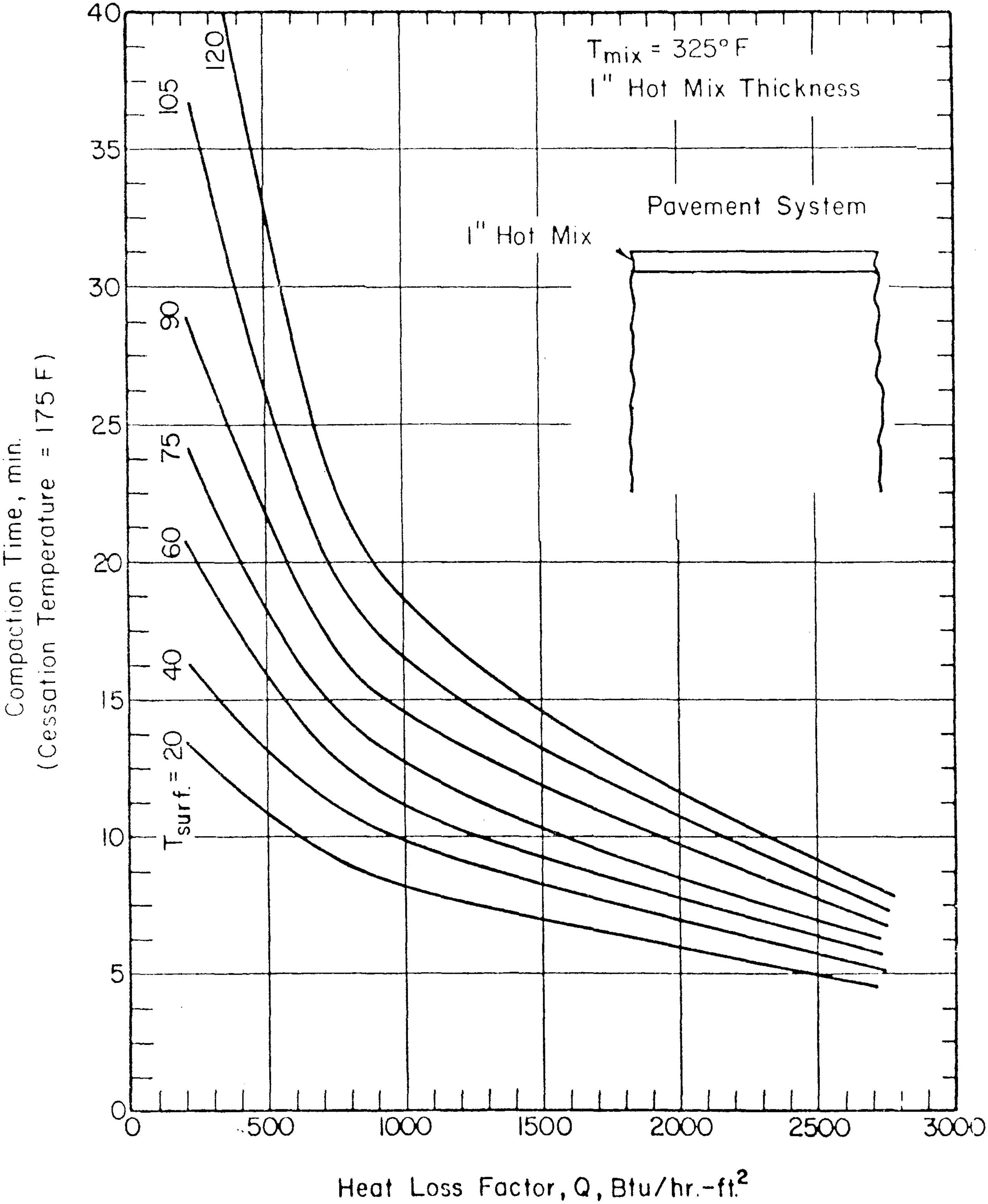

Figure 5: Compaction Time Curves

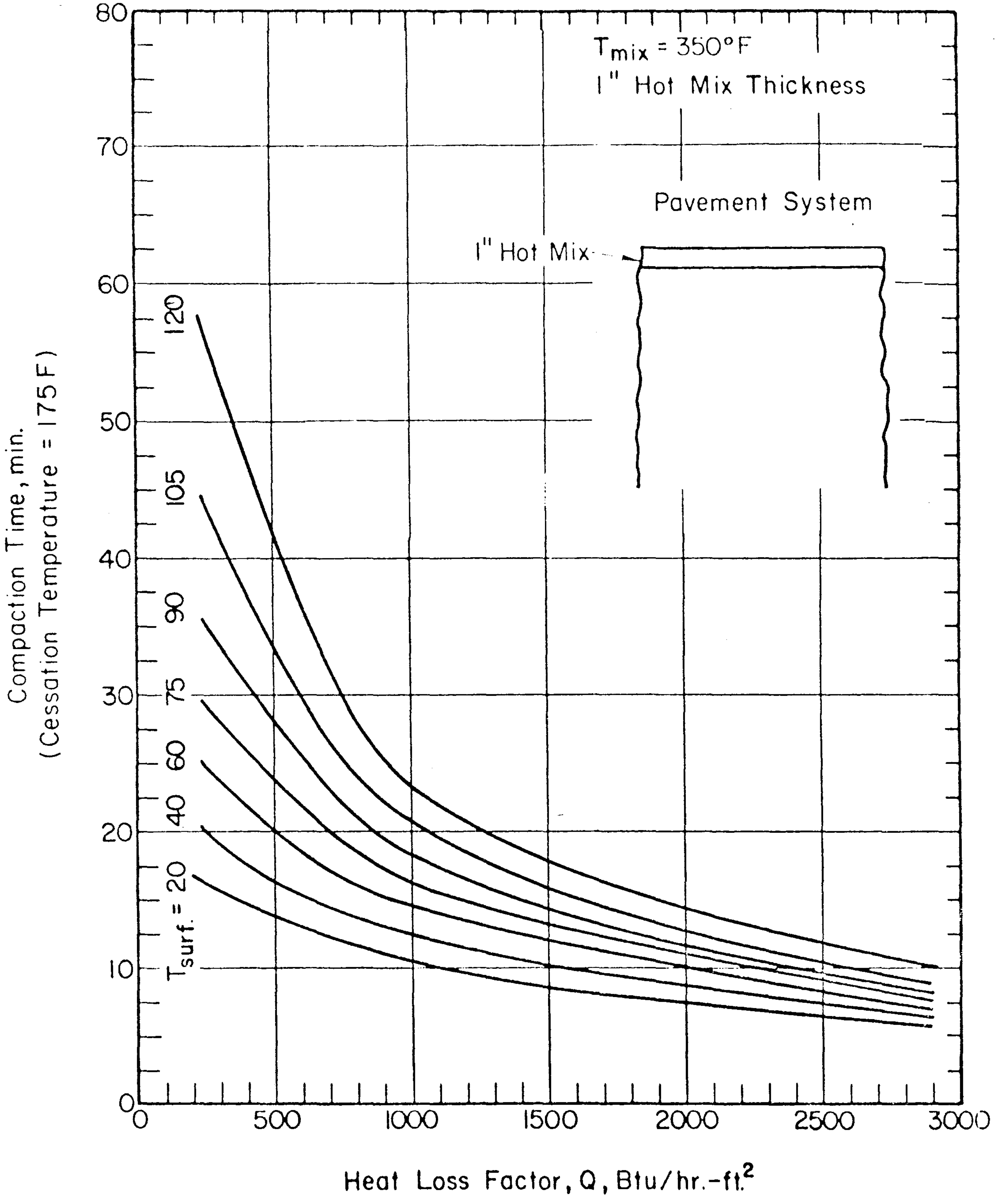

Figure 6: Compaction Time Curves

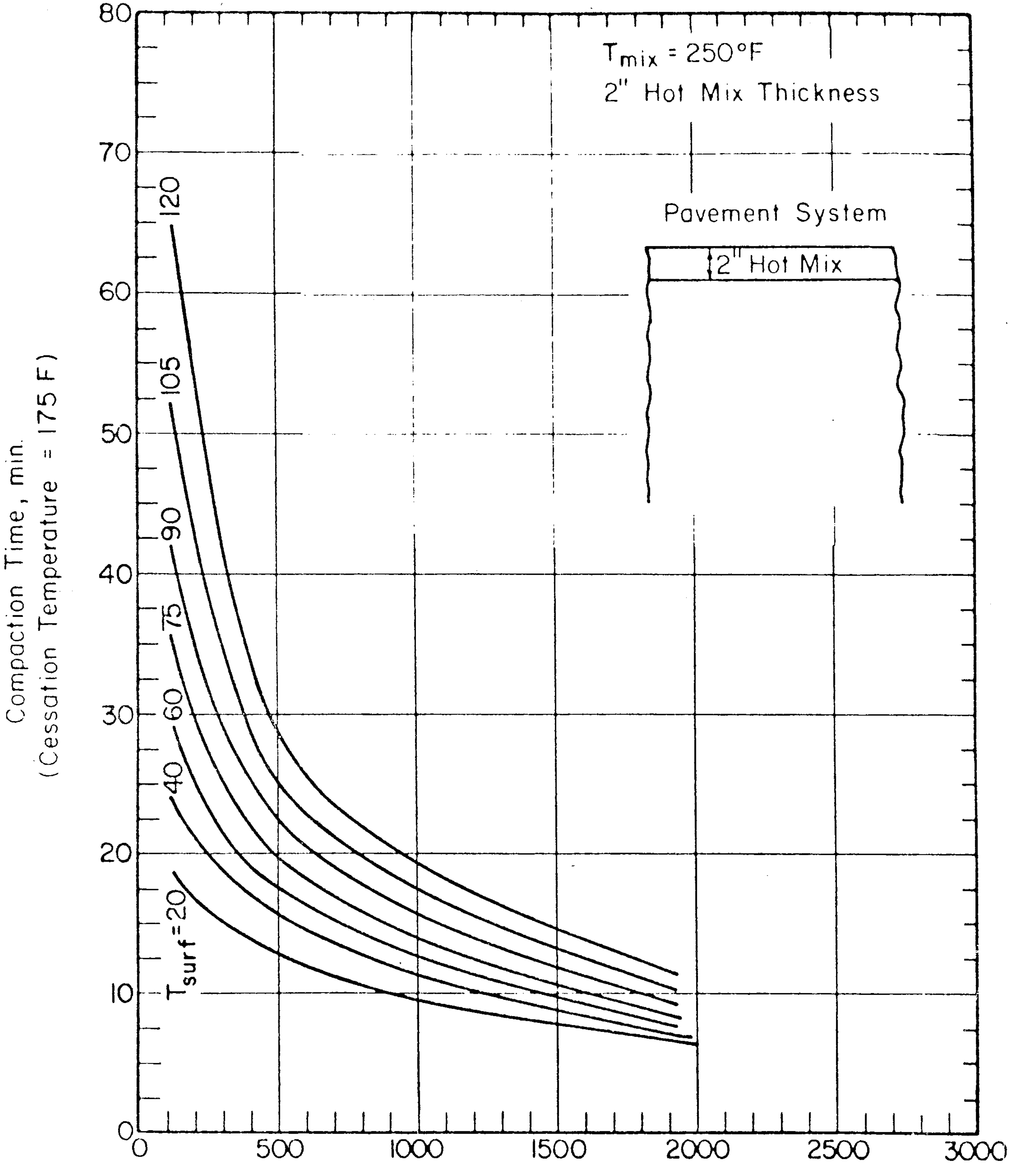

Figure 7: Compaction Time Curves

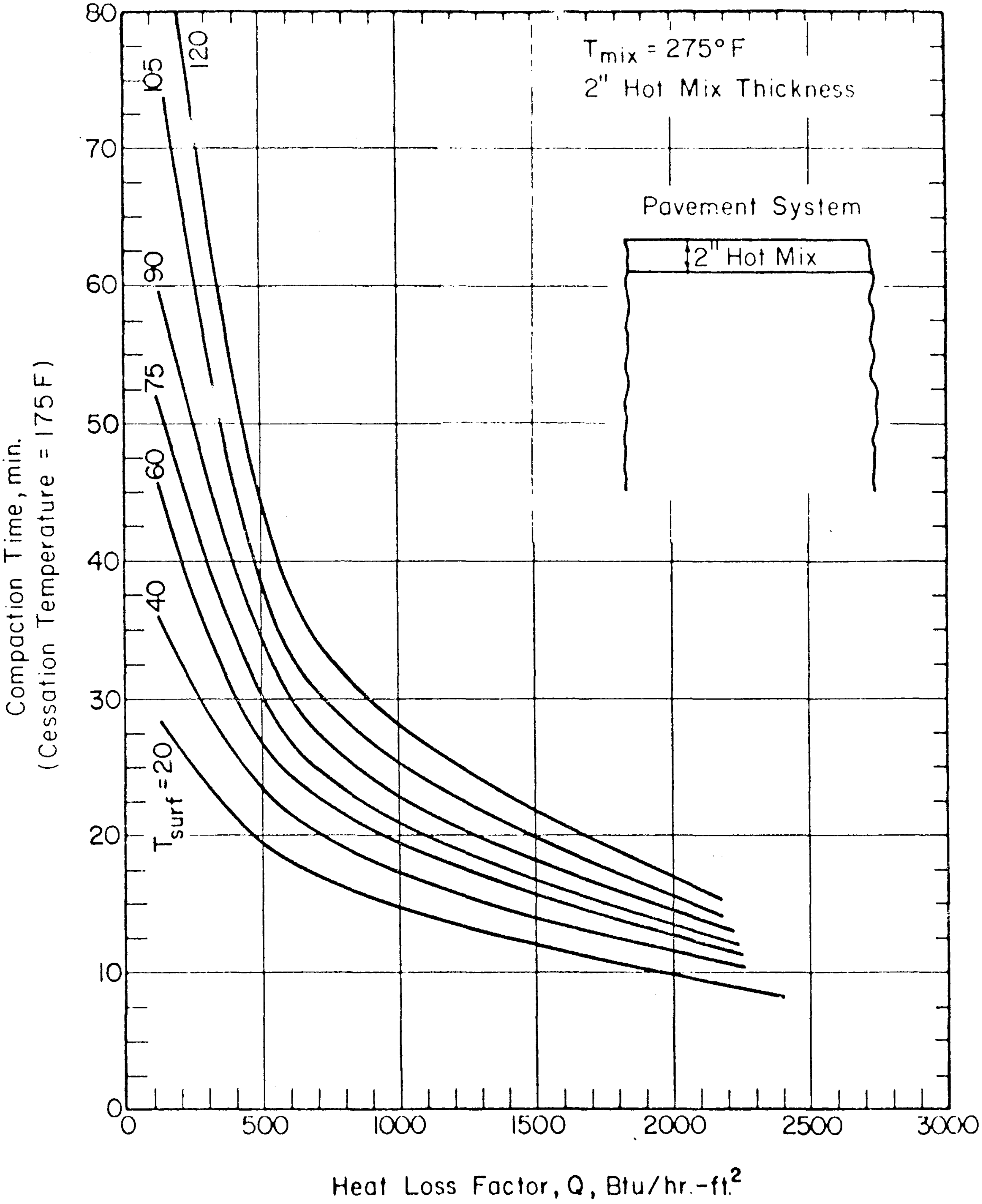

Figure 8: Compaction Time Curves

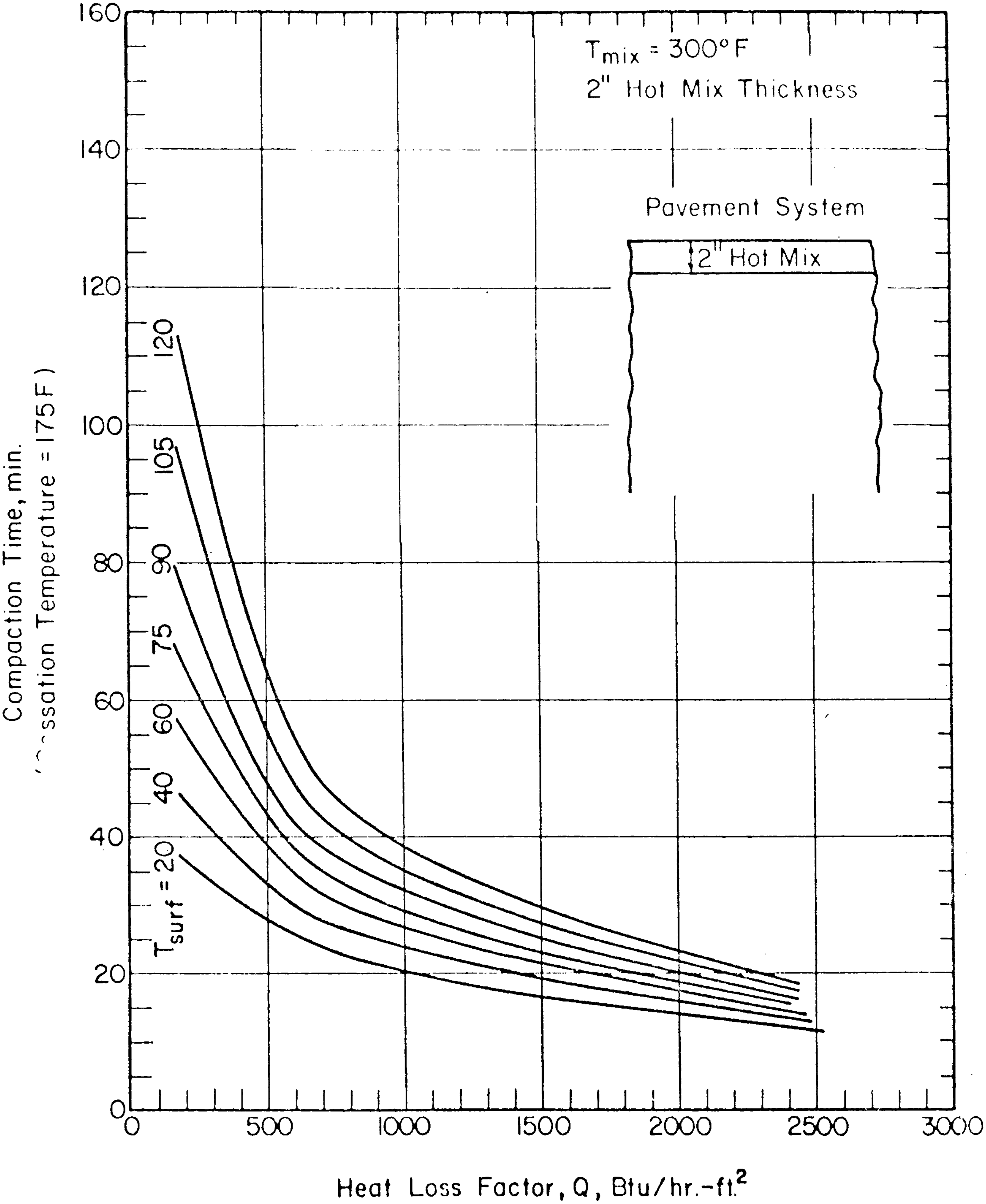

Figure 9: Compaction Time Curves

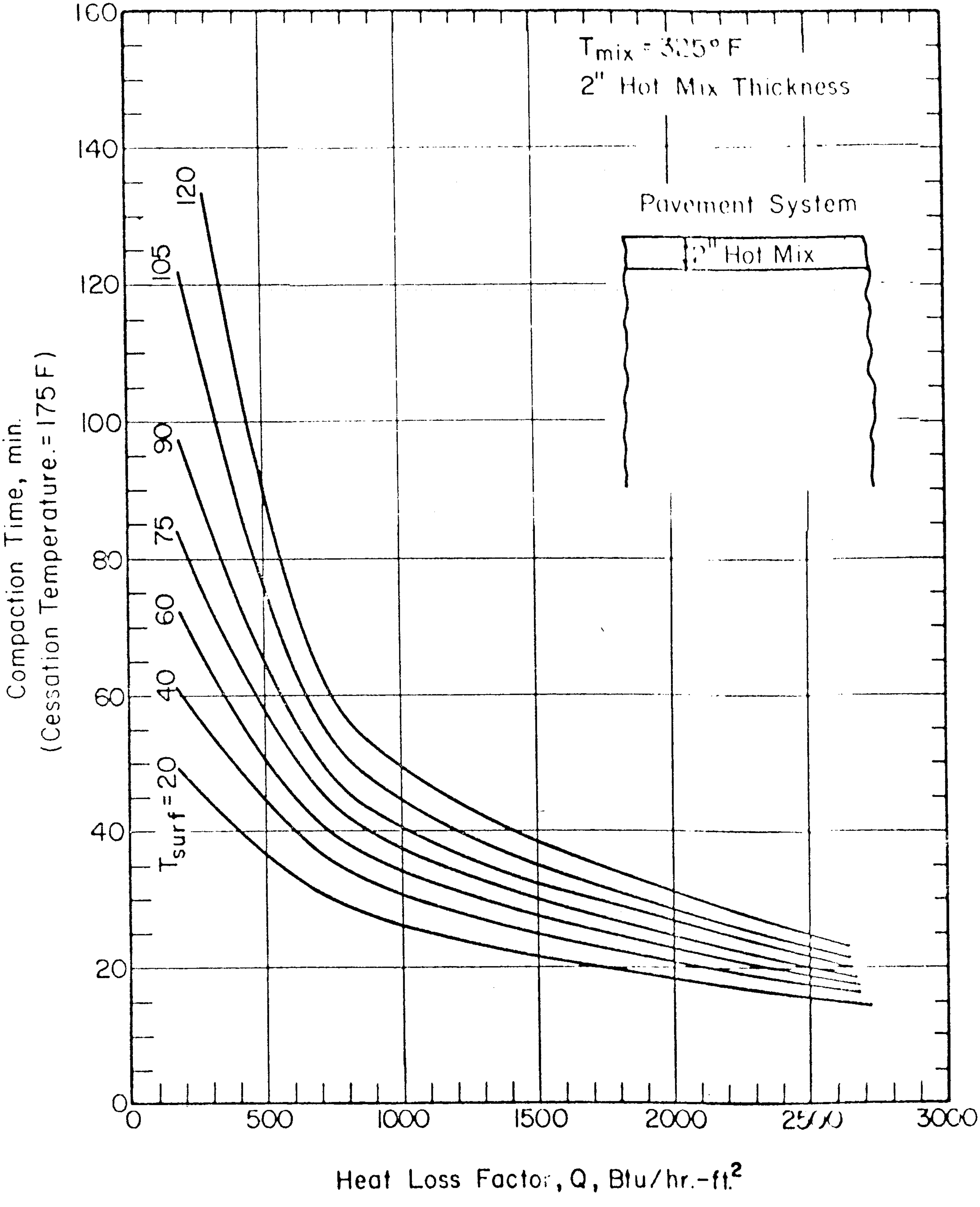

Figure 10: Compaction Time Curves

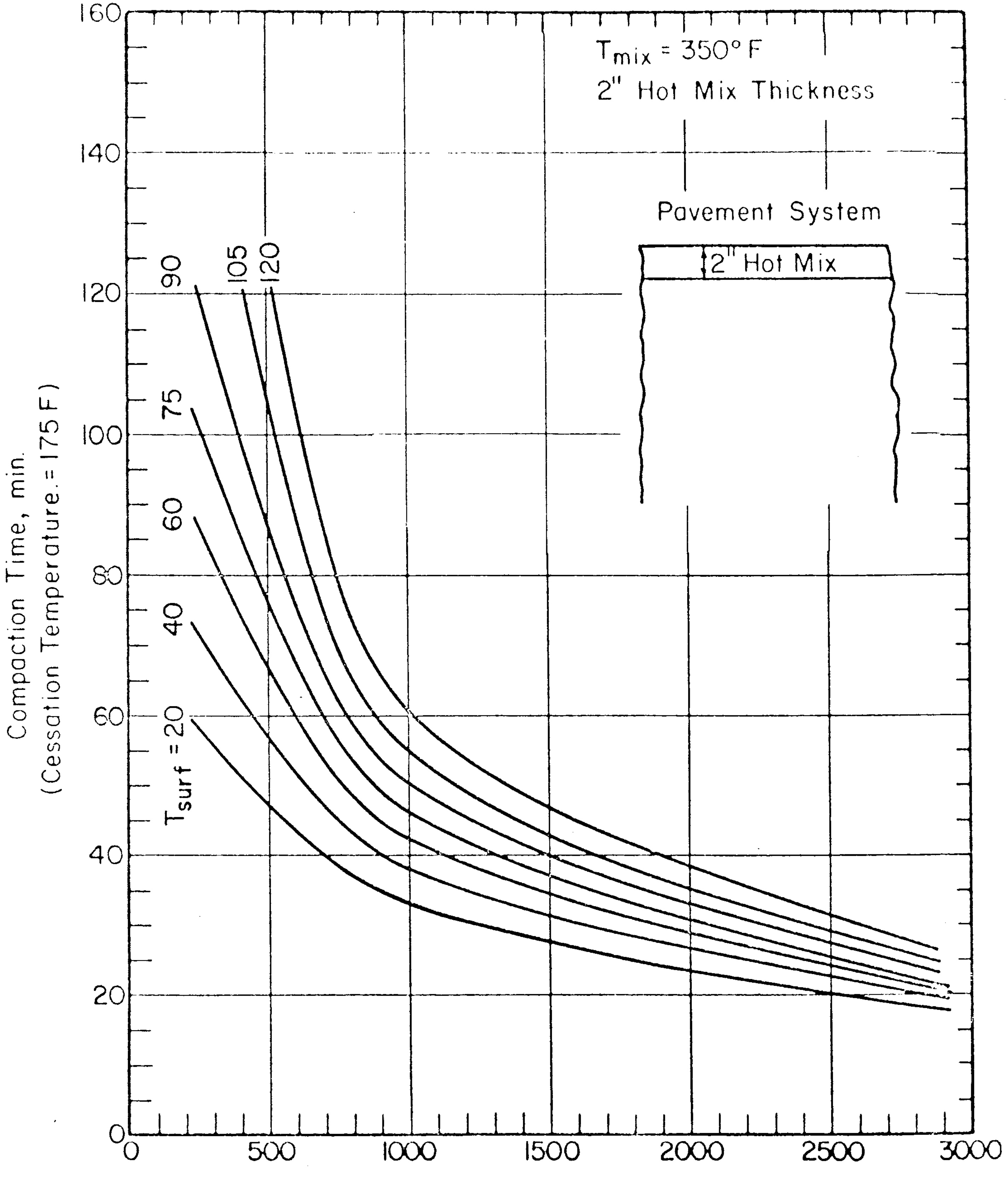

Figure 11: Compaction Time Curves

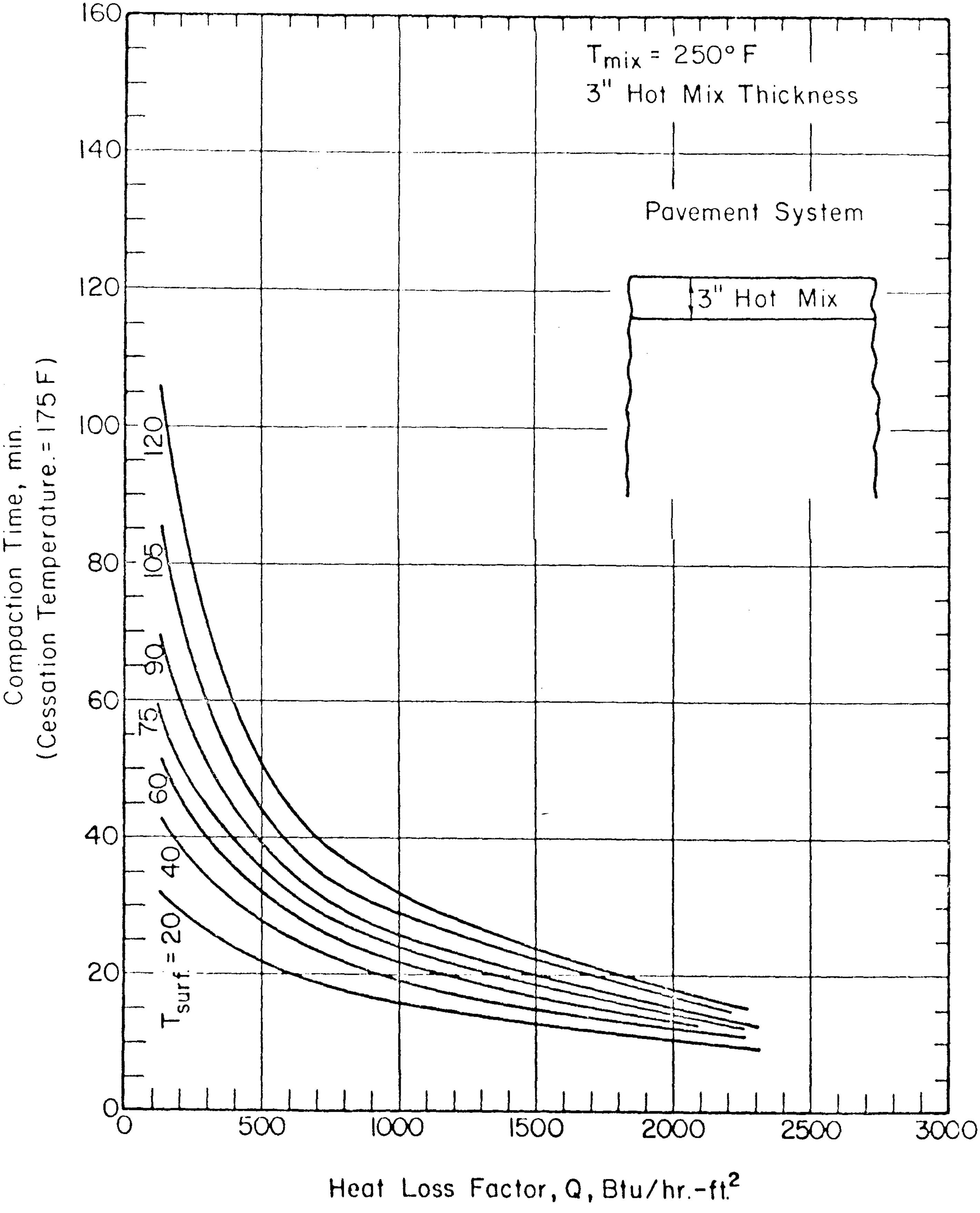

Figure 12: Compaction Time Curves

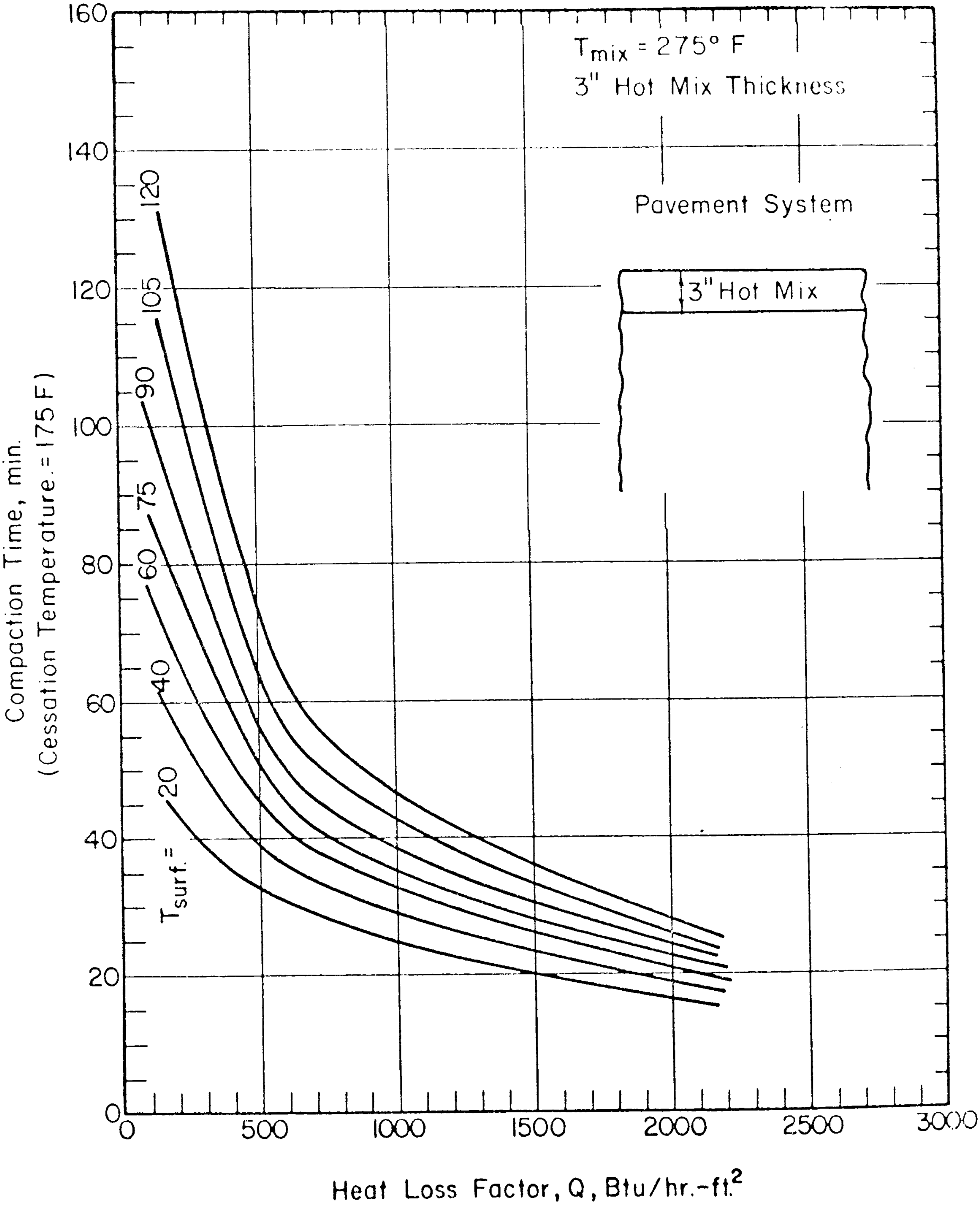

Figure 13: Compaction Time Curves

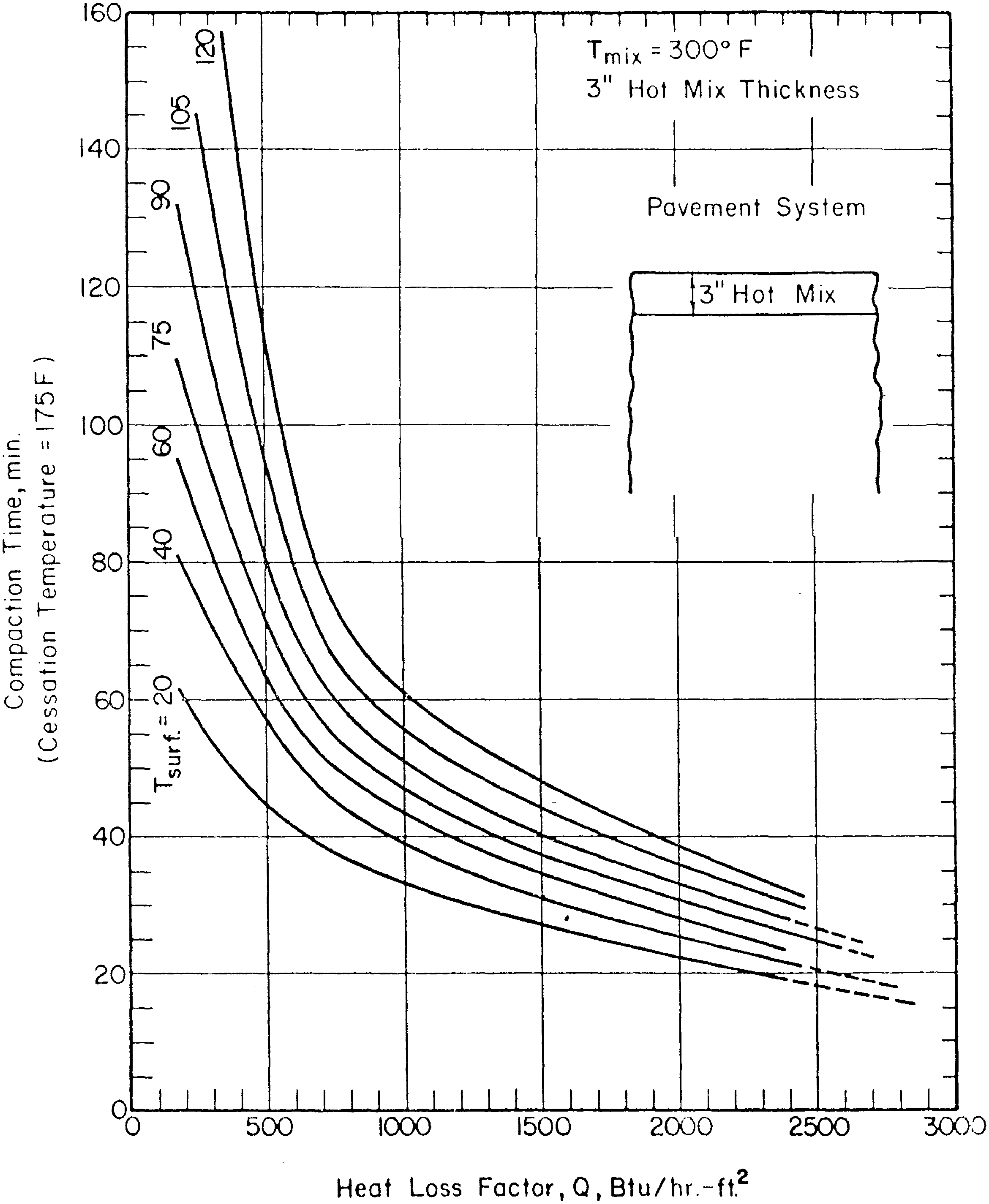

Figure 14: Compaction Time Curves

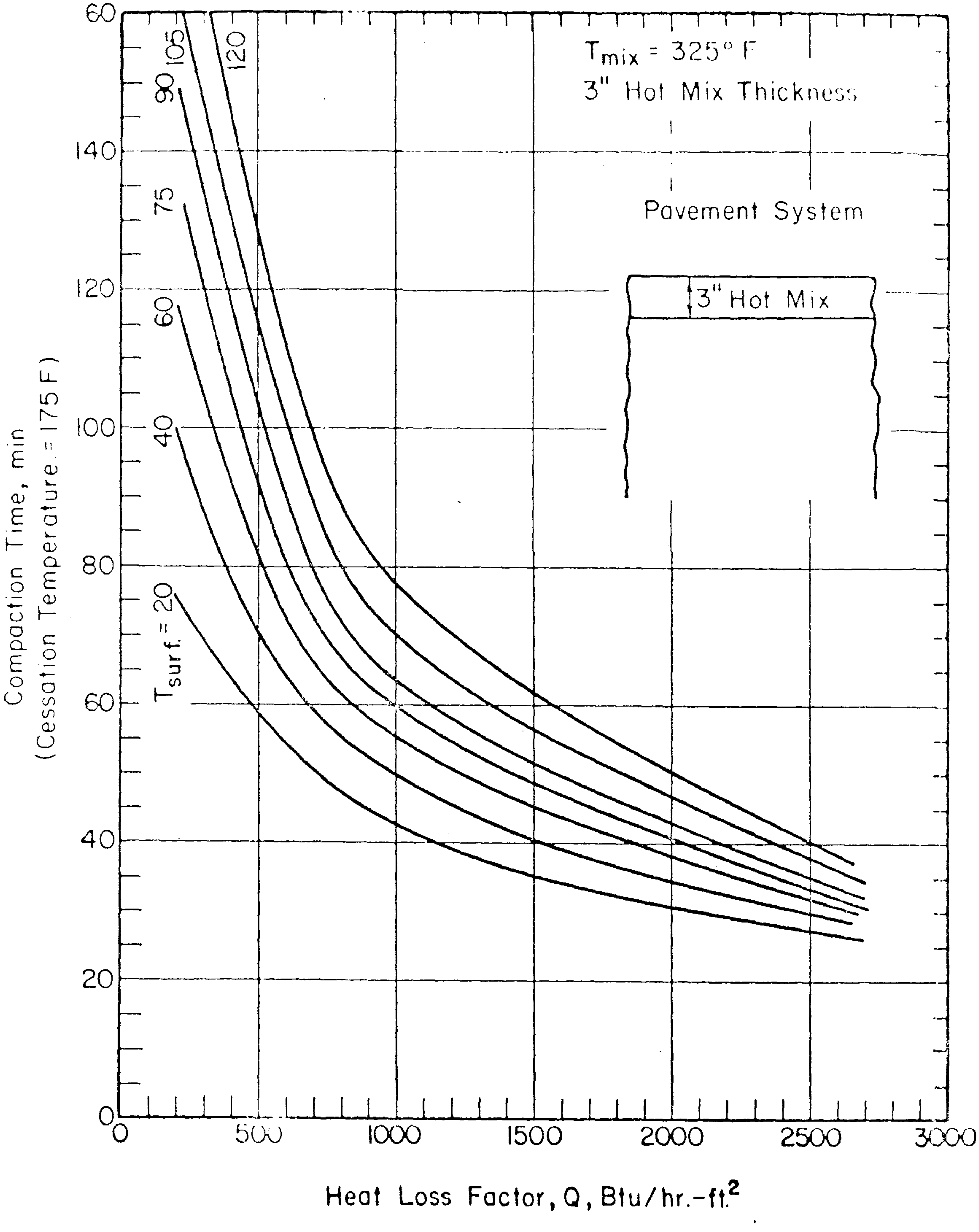

Figure 15: Compaction Time Curves

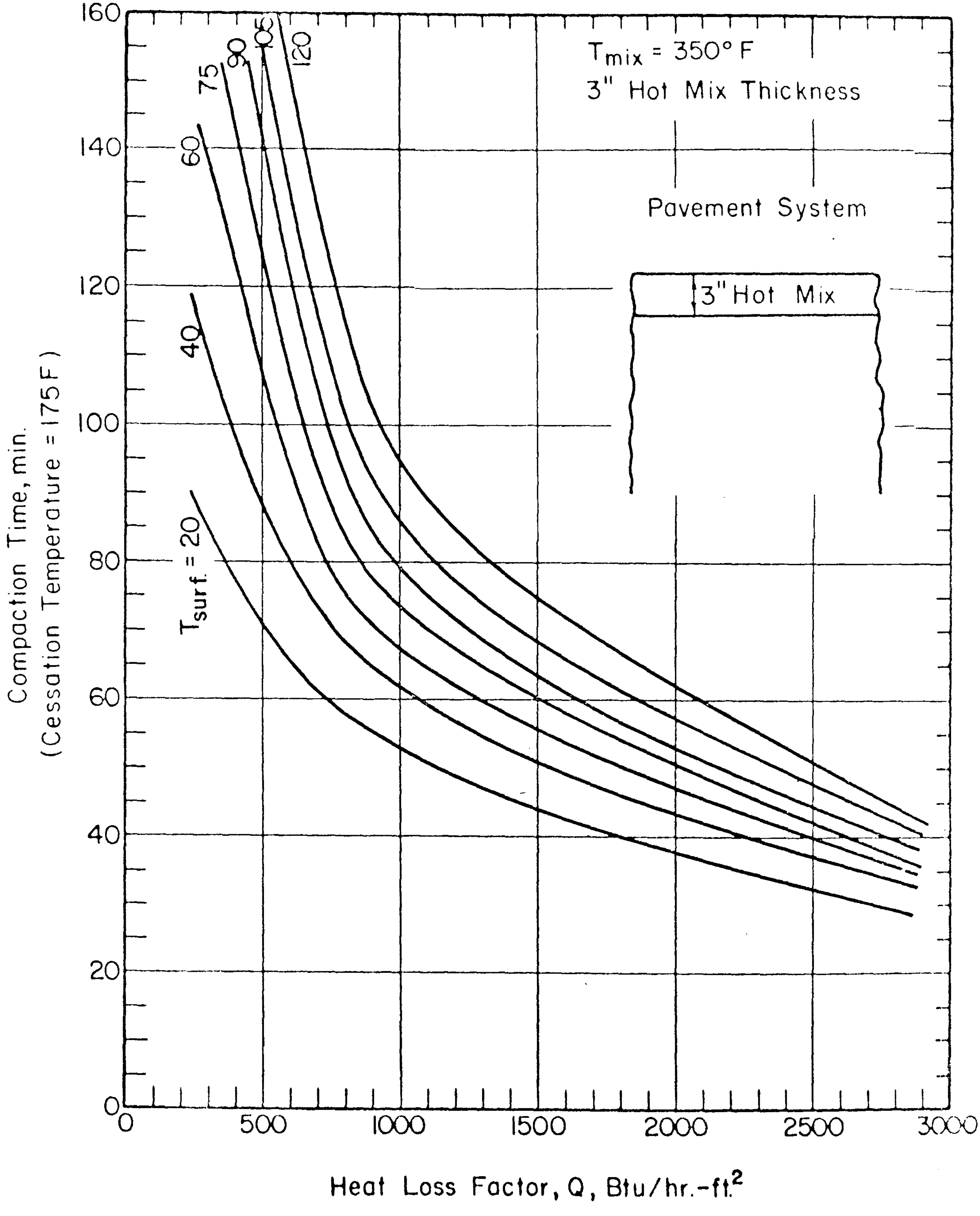

Figure 16: Compaction Time Curves

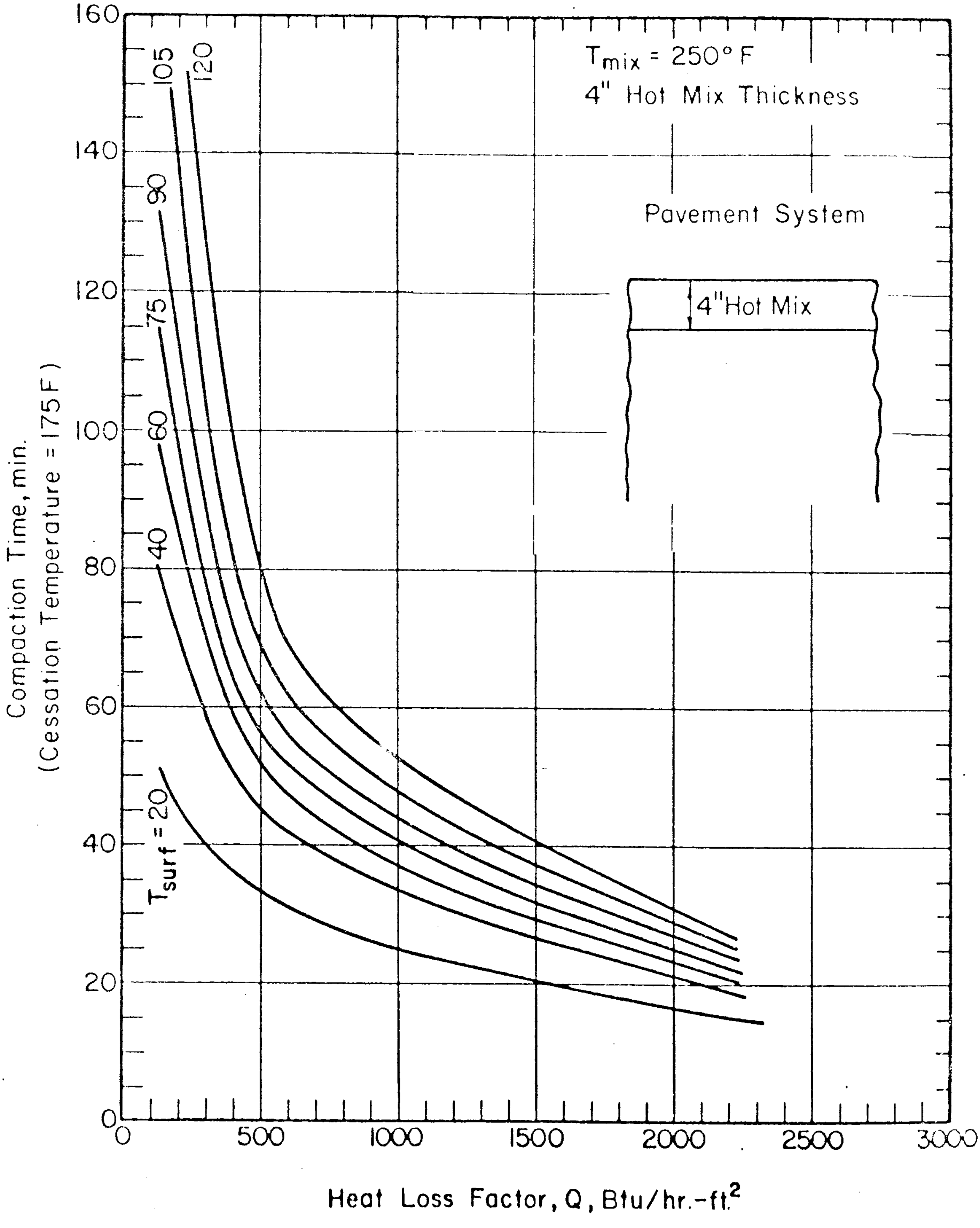

Figure 17: Compaction Time Curves

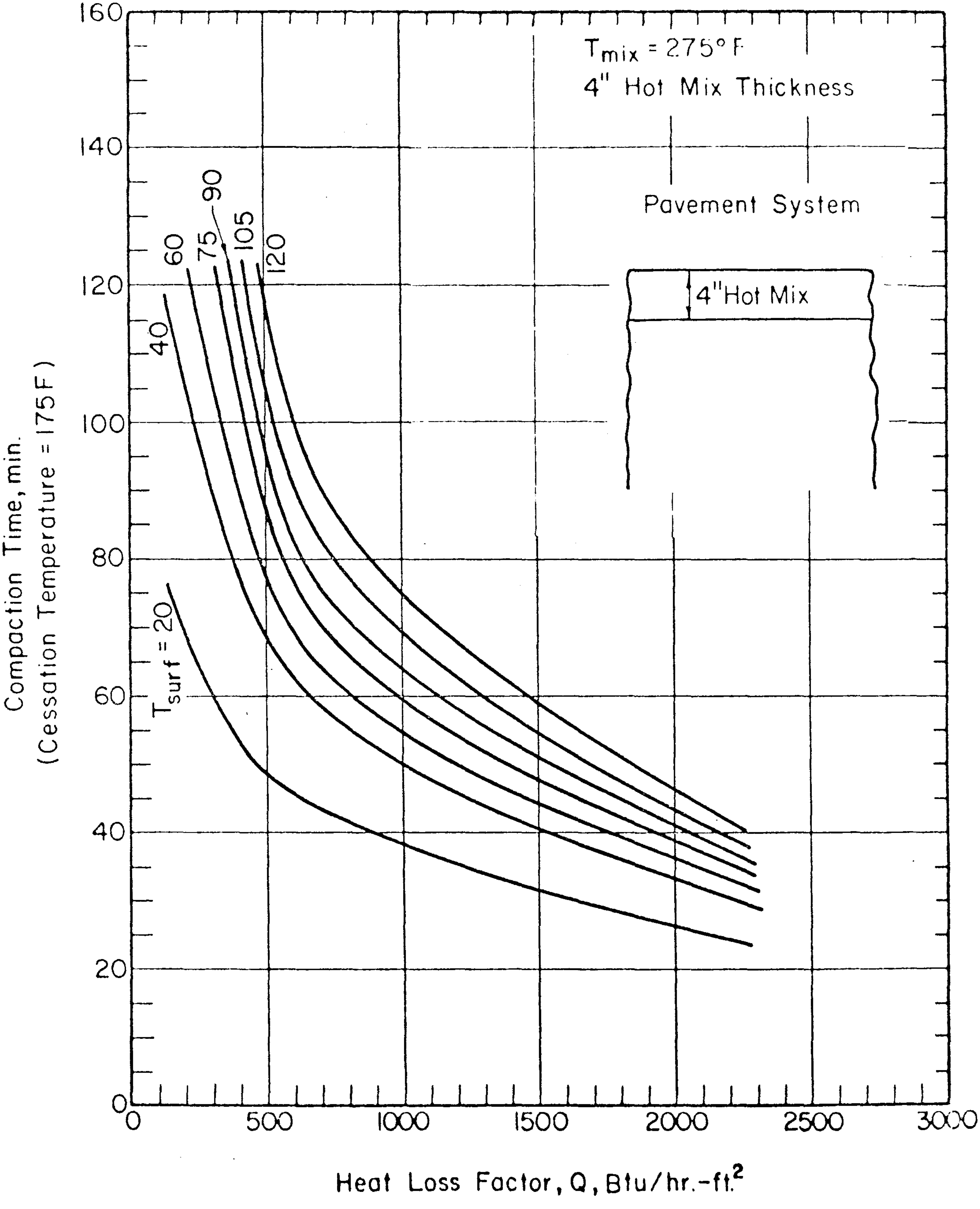

Figure 18: Compaction Time Curves

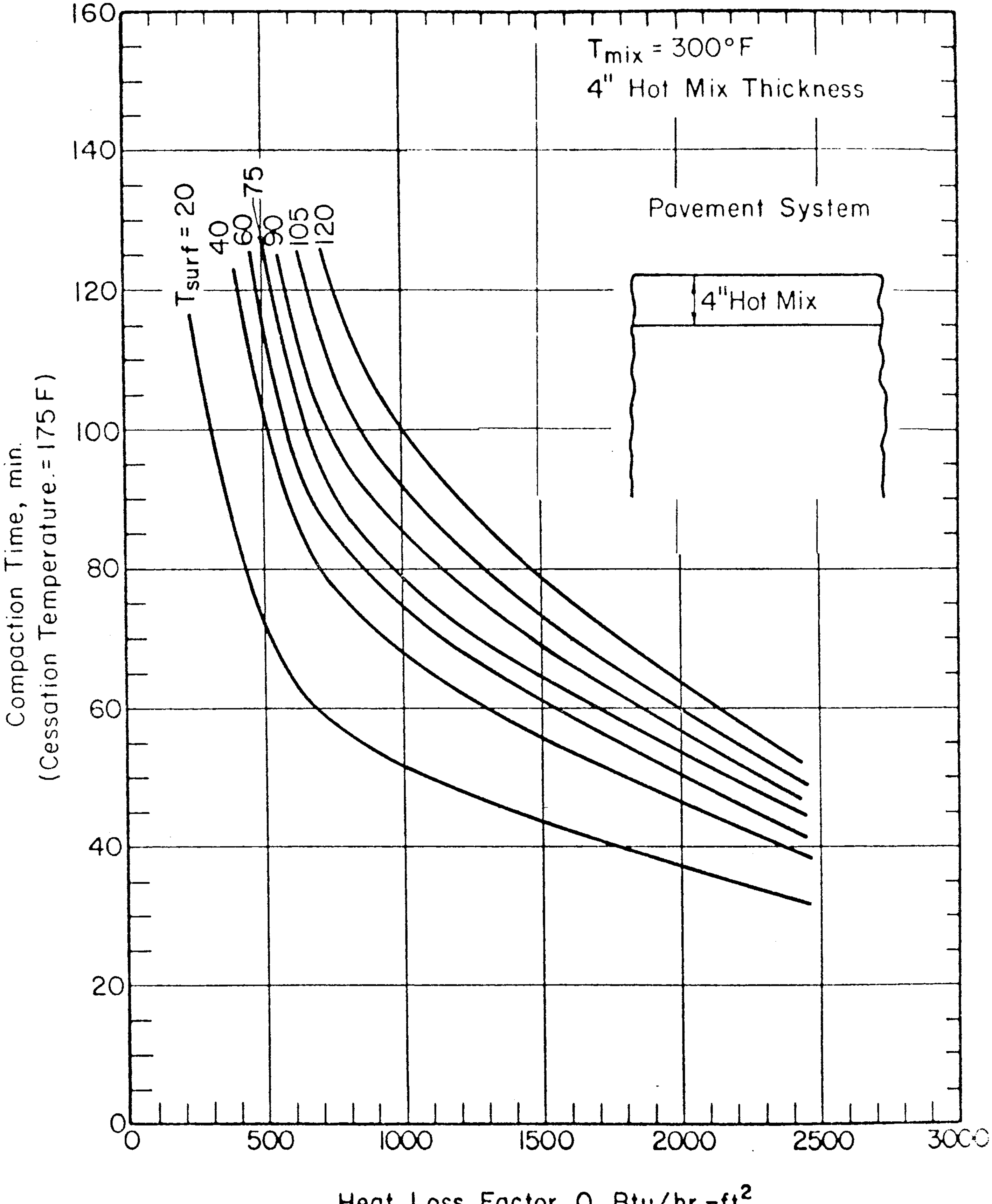

Figure 19: Compaction Time Curves

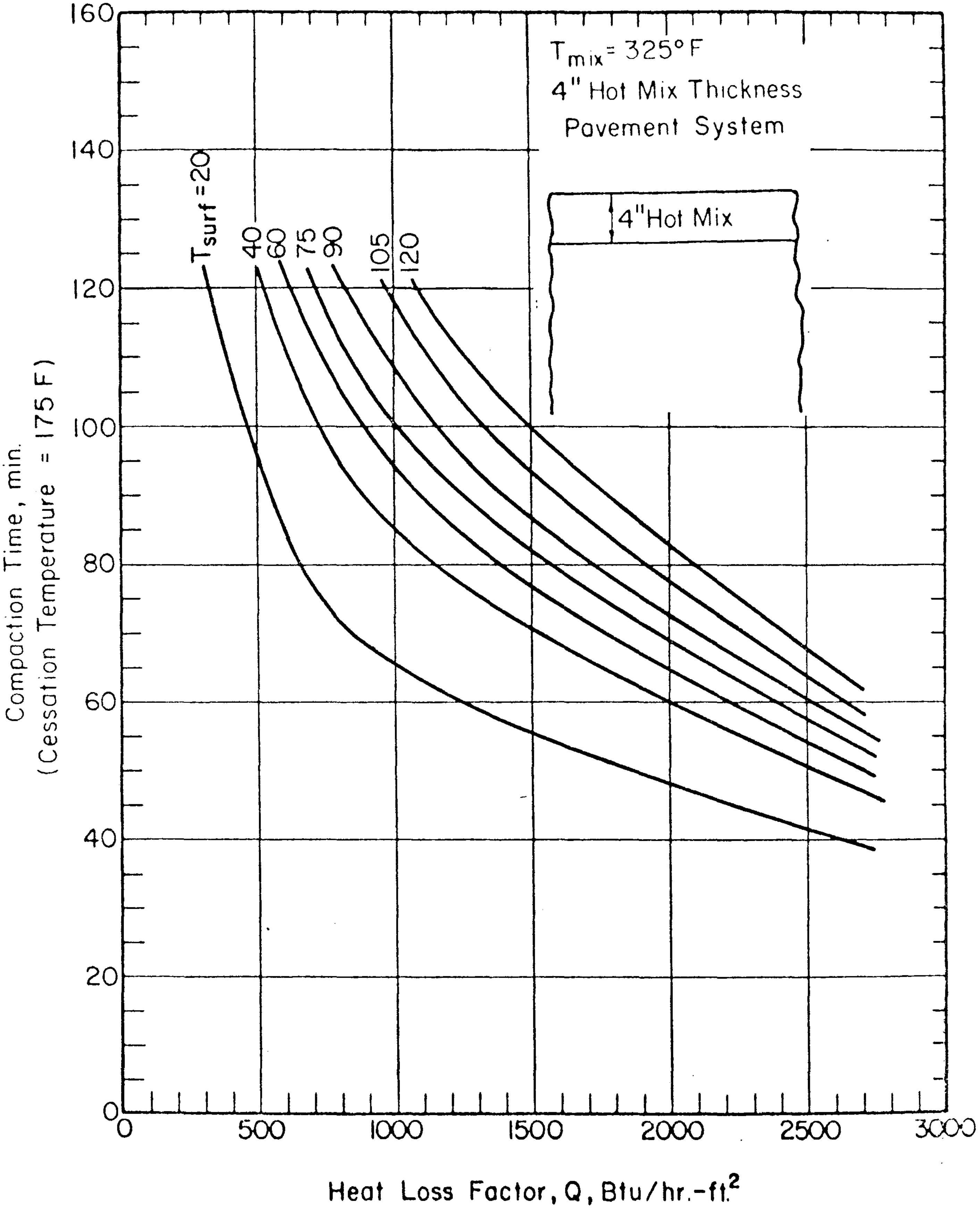

Figure 20: Compaction Time Curves

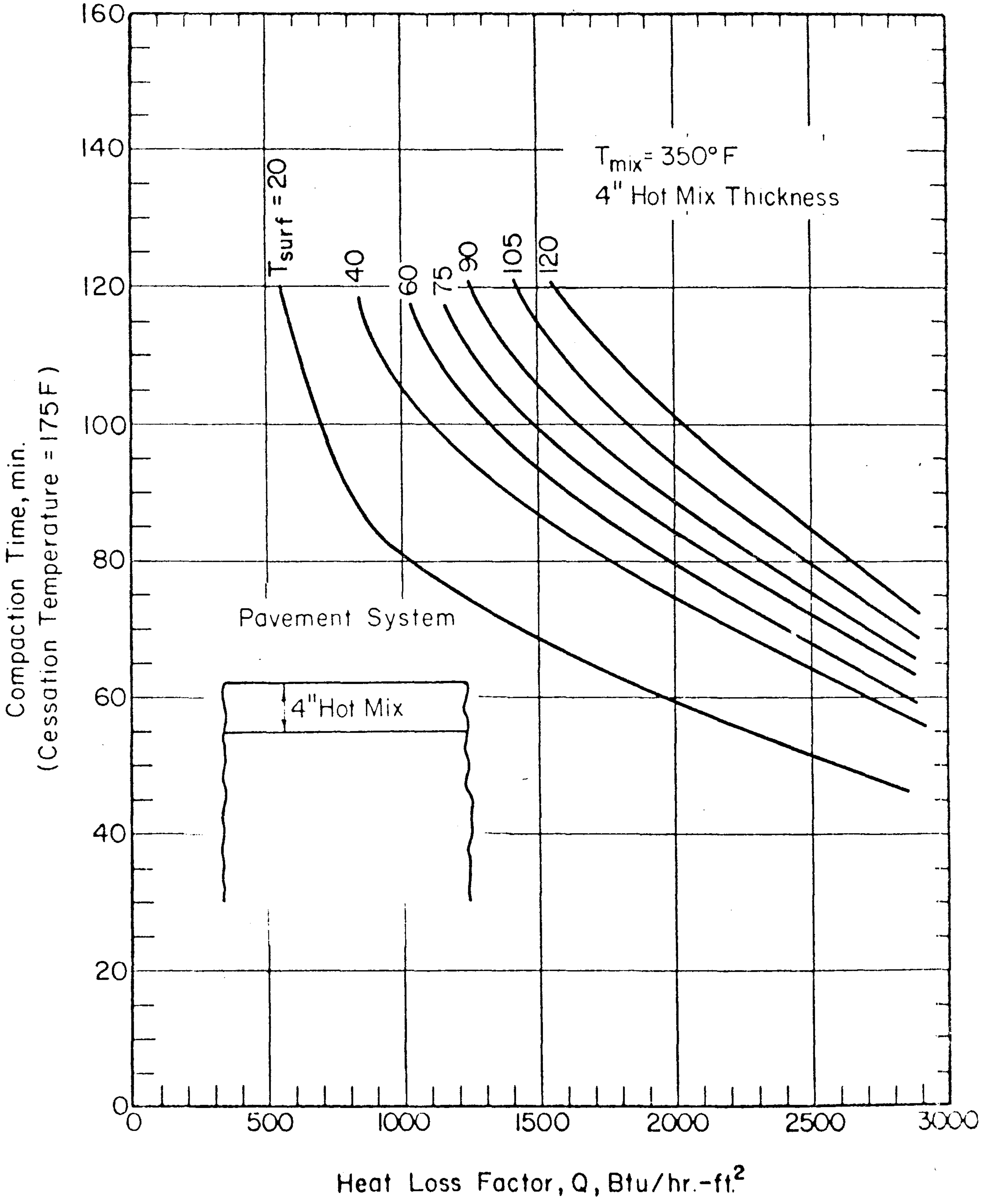

Figure 21: Compaction Time Curves

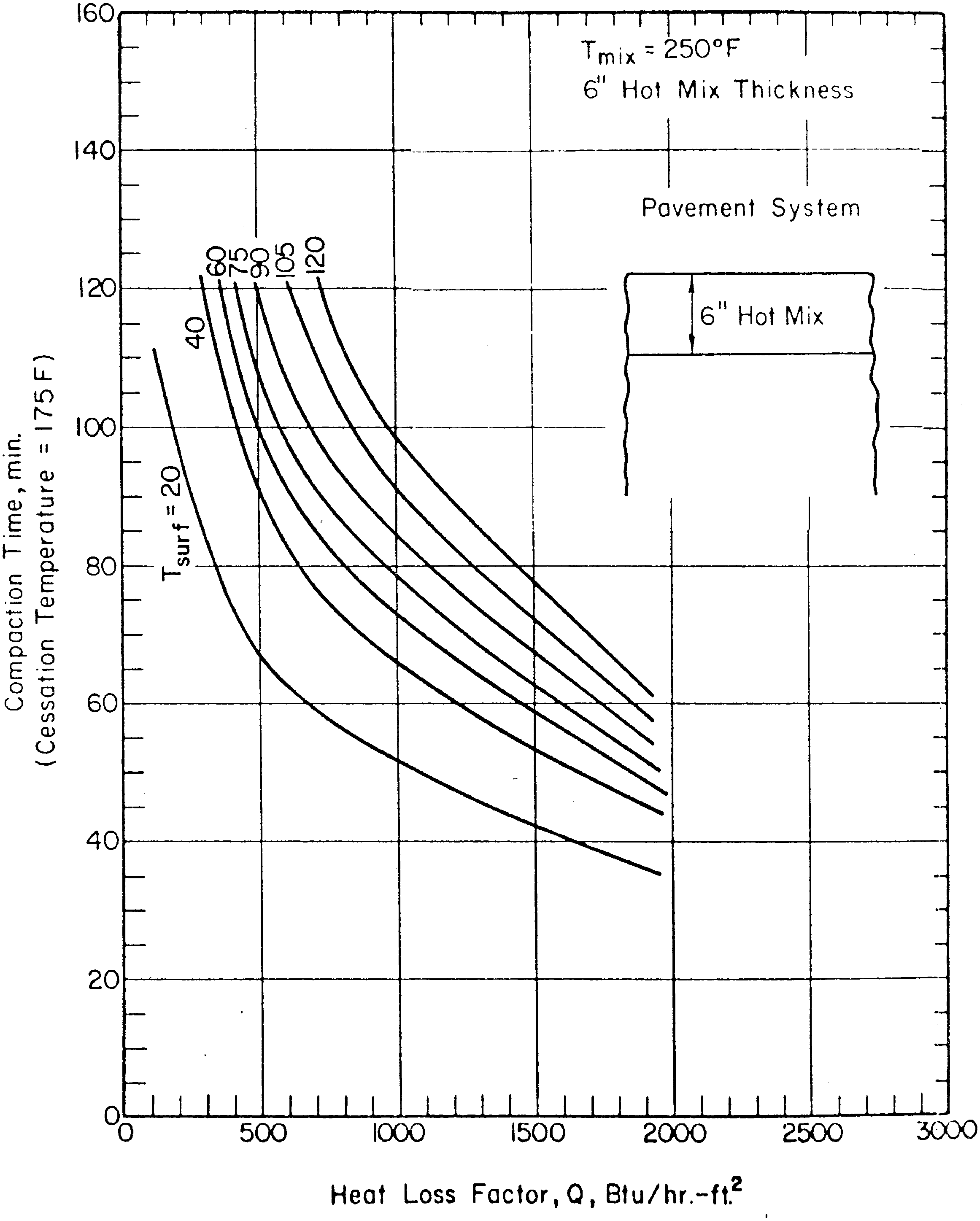

Figure 22: Compaction Time Curves

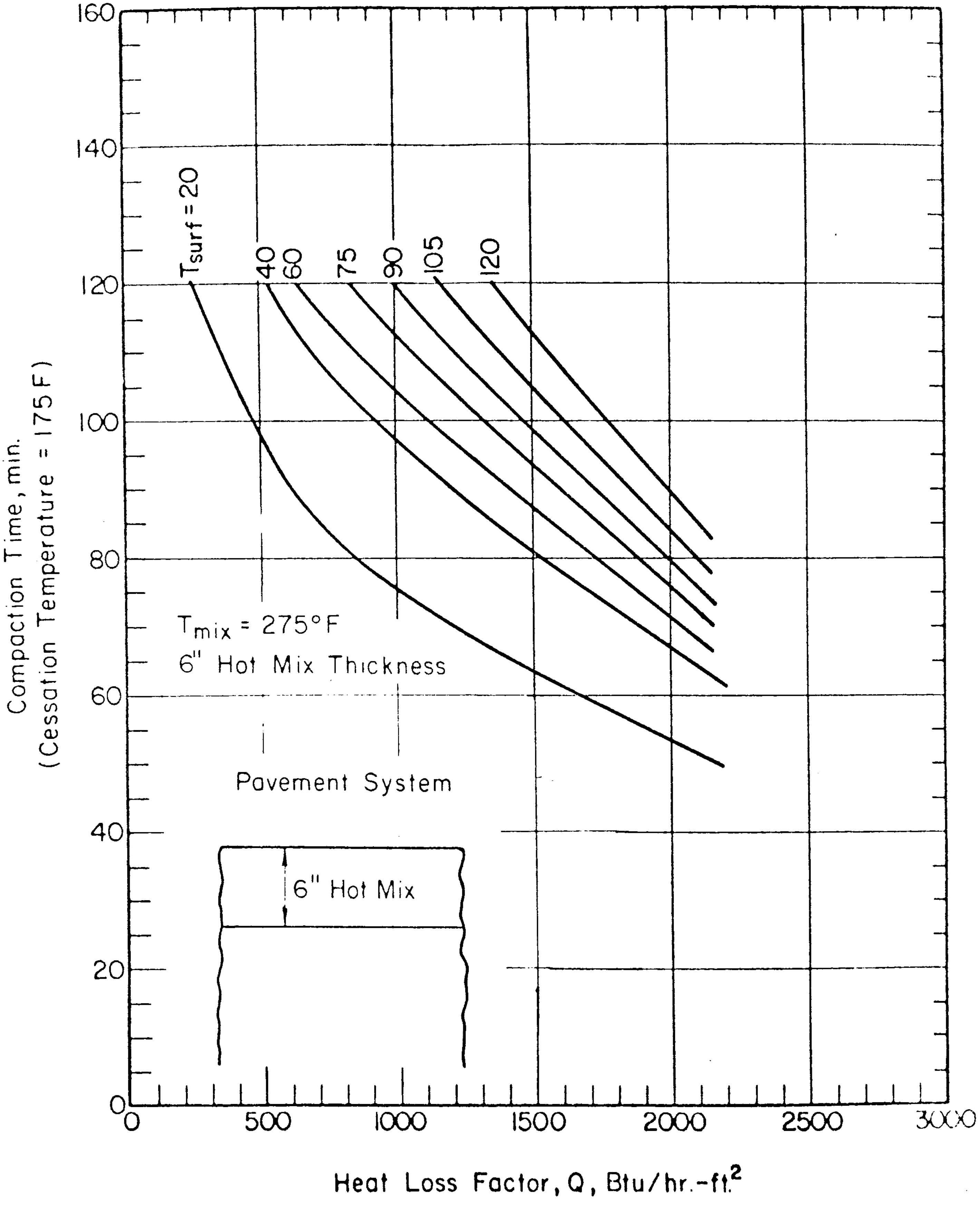

Figure 23: Compaction Time Curves

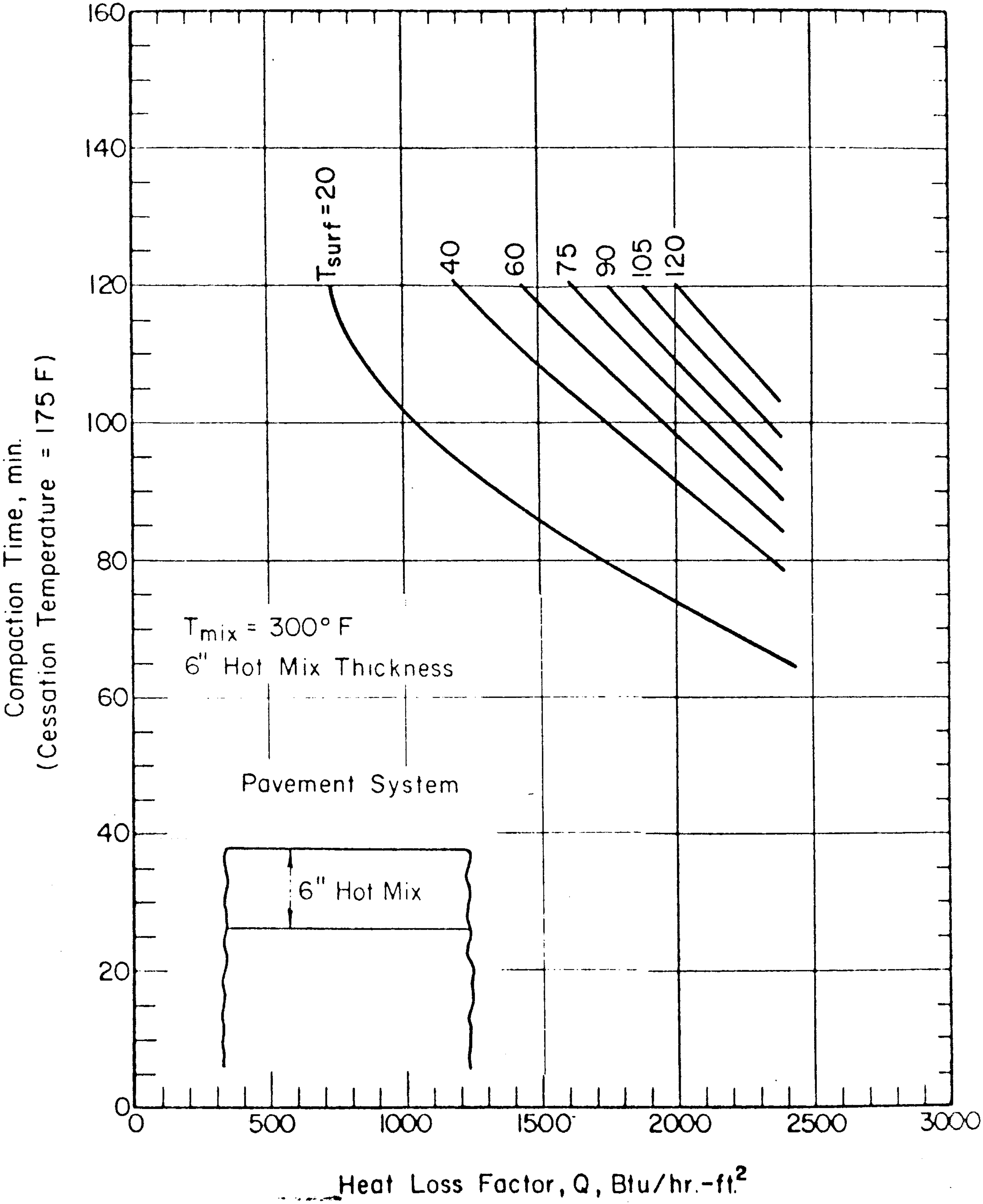

Figure 24: Compaction Time Curves

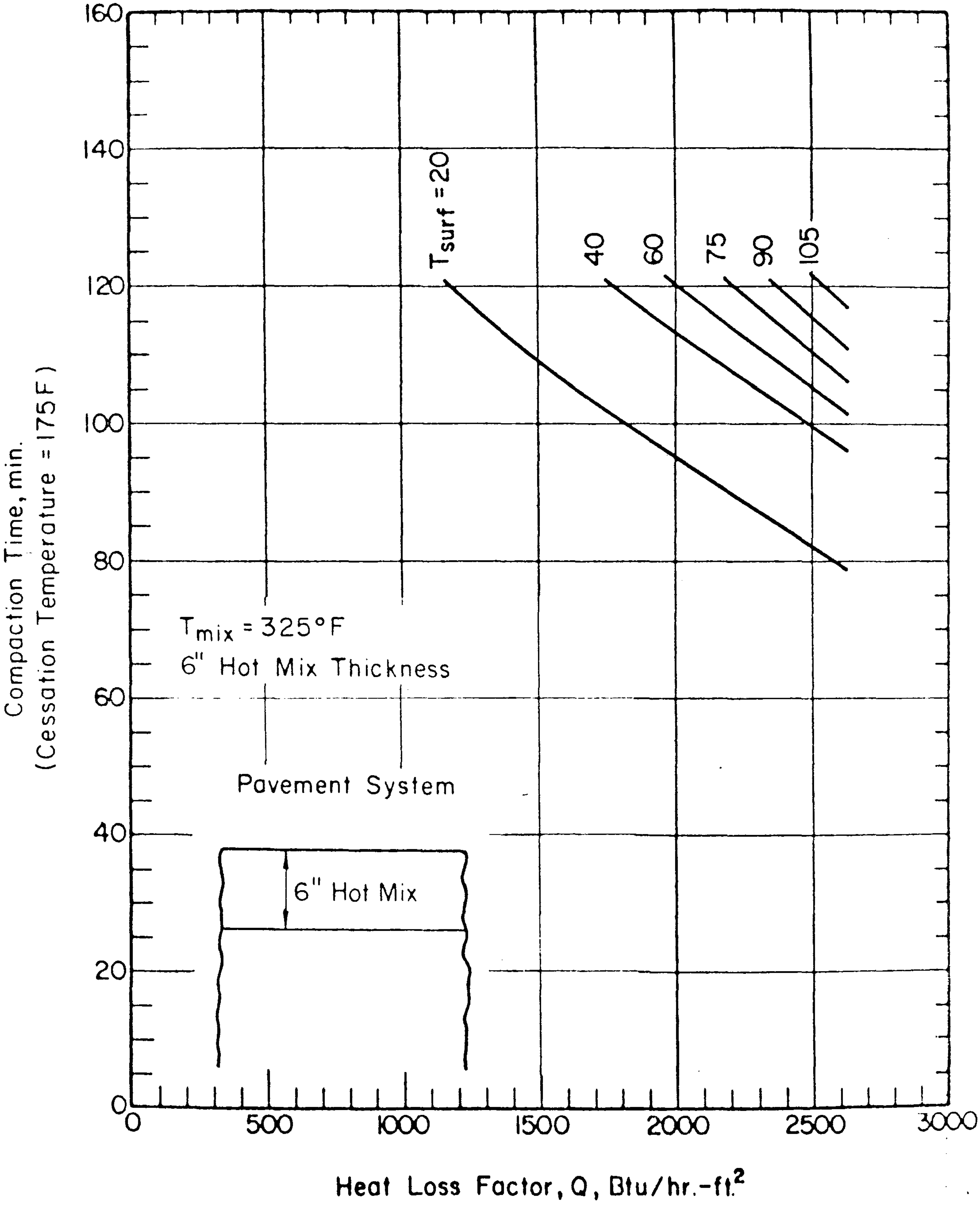

Figure 25: Compaction Time Curves