THERMAL ENERGY STORAGE TESTING FACILITY

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PROJECT OUTLINE

Project Title: Operation of a Storage Heater Test Facility

Principal Investigator: J. Asbury

Organization: Argonne National Laboratory
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Project Goals: Determine the thermal performance of resistance storage heaters in respect to current standards. Propose additional standards as appropriate.

Design and construct a storage heater test facility at Purdue University with capability for measuring the performance of electric resistance heated storage units. Compare performance of commercial units based on existing standards. Propose additional performance standards as appropriate.

Project Status: Calorimeter construction is completed, and testing procedures are being prepared. Tests of storage heaters are in progress.

Contract Number: 31-109-38-4666

Contract Period: October, 1978 to September, 1980

Funding Level: $100K

Funding Source: Argonne National Laboratory

THERMAL ENERGY STORAGE TESTING FACILITY*

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SUMMARY

Development of a prototype testing facility for electrically heated thermal energy storage units is being pursued. Test procedures are being evaluated and verified by means of simultaneous redundant measurements and analysis. The quality of measurements obtained with the use of a calibrated calorimeter chamber has been improved. Testing of commercially available units is being performed, and experience gained in this activity will be used to further refine and substantiate the test procedures being formulated.

INTRODUCTION

This project deals with the development of a facility for testing of residential electrically heated thermal energy storage (TES) units. Experiments are presently being conducted with devices which utilize high heat capacity ceramic bricks as the energy storage medium. Large central units are now available for replacing conventional residential furnaces. Also on the market are small self-contained room-size units which avoid the necessity for ductwork and a central air handling system.

Energy charging of these devices occurs at night using less expensive off-peak electrical energy. During this period the electrical heaters inside the unit are activated, heating the ceramic bricks to a high temperature. Air then is caused to flow over the bricks intermittently throughout the day and evening as required to maintain the residence air temperature. The air flowing over the bricks is heated during this process, and the bricks are correspondingly cooled so that their temperature level is eventually lowered thus preparing them for acceptance of another energy charge during the next night-time period.

Use of off-peak electrical energy with TES systems makes it possible for a utility to increase its total energy output with a given quantity of generating capacity. With fewer customers drawing appreciable amounts of energy during the day, the daily peak is reduced. Concurrently, the usual decrease in load at night is reduced as more customers draw energy during this period for charging of TES units. This concept has been in use in some areas in Europe for several years. More recently it has been introduced in the U.S. on a small scale, mostly on an experimental basis by certain utilities with a limited number of customers. As a result, field test data are being collected by a

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* This project is supported by Argonne National Laboratory, Energy and Environmental Systems Division, Special Projects Group, under Contract No. 31-109-38-4666.

number of organizations, including the utilities themselves, the Electric Power Research Institute and Argonne National Laboratory.

Although electrically heated TES units are now on the market in the U.S., standard performance testing procedures have not yet been established in this country. Available information which can assist in the development of such procedures includes a German Standard, DIN 44572, which has been established specifically for electrically heated TES units. Within the U.S. a standard has been established for testing of other types of TES units by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), ASHRAE Standard 94-77. Both of these documents have been quite helpful in guiding the present work.

Currently ASHRAE Standards Project Committee 94A is in the process of writing descriptions of standard test procedures for electrically heated TES units. Simultaneously, experimental and analytical work is being pursued in this project in order to assist ASHRAE in its effort. Personnel of Argonne National Laboratory and Oak Ridge National Laboratory provide coordination by maintaining contact with ASHRAE Committee 94A and by monitoring the activities conducted in this project.

GENERAL DESCRIPTION OF THE PROJECT

The objective of this project is the development of a prototype TES testing facility that can be duplicated at established commercial or government laboratories, or at TES manufacturers' R & D laboratories. In addition to defining the characteristics of the test apparatus, appropriate test procedures are to be defined and verified. The goal is to achieve the type of facility and associated methods that can be easily and economically used elsewhere. Thus, simplicity is desired, as opposed to tests which would be elaborate, expensive and time consuming. Complexity is reluctantly added only when the simplest procedures fail to yield results of sufficient accuracy.

Quantities to be identified by tests conducted with a particular TES unit include total energy charge, heat loss during charging and standby, and rate of delivery of energy during discharge. For the larger central units the rate of energy delivery can be calculated after measuring the air flow rate through the device and the temperature difference between the inlet and outlet air. This type of test can be performed with the unit placed in a typical laboratory setting. Heat losses are not measured directly in this case, but uniformity can be obtained from test to test by requiring that the laboratory air temperature be maintained within a specified range.

Certain advantages are obtained by testing the smaller room-size units inside a calibrated calorimeter chamber. Once the chamber has been properly calibrated the heat loss from a TES unit during charging and standby and the rate of energy delivery during discharge can be determined by measuring the inlet to outlet air temperature difference across the chamber. Measurement of the air flow rate through the chamber is not required either during calibration or during the test of the TES unit, according to the German Standard DIN 44572.

In this project various test methods are being studied both experimentally and analytically. Simultaneous redundant measurements are made where possible in order to establish the validity of the procedures. For example, although the calorimeter method does not require a direct measurement of the air flow rate, a standard nozzle has been installed for this purpose in order to provide an independent determination of the heat loss from the calorimeter chamber. Also, electrical input energy during charging of a TES unit is determined by 3 techniques: (1) by use of a calibrated watt-hour meter, (2) by means of a conventional wattmeter and (3) by electrically integrating the signal from a watt transducer. By making these additional measurements it is possible to learn more about the magnitudes of the quantities of interest and to verify the accuracy and precision with which they can be determined from the measurements. It is hoped that once this kind of verification has been accomplished in this project, eventual recommended test procedures will involve the smallest number of straightforward measurements possible for meaningful determinations of the quantities of interest.

Figure 1 contains a photograph showing one of the large central TES units (foreground) and the calorimeter chamber which has been fabricated for testing of the room-size units. The blower which draws air through the chamber is on the left. Air enters the chamber on the right. Figure 2 shows the opposite side of the chamber. Some of the instrumentation can be seen in this view as well as a small TES unit which is ready for installation in the chamber for testing.

RESULTS AND DISCUSSION

The calorimeter chamber was designed and fabricated to keep heat losses small. The chamber walls and door are lined on the inside with a layer of Styrofoam approximately 10 cm thick. The outlet consists of a flaired rectangular section which is followed by a duct of round cross-section. The round portion is well insulated on the outside with glass wool. A schematic diagram of the essential features of the system illustrating the various energy flow rates is given in Figure 3. Both analysis and measurements indicate that the heat loss from the chamber and from the outlet duct is typically about 15% of the heat delivered to the interior of the chamber by the heating unit.

For purposes of calibration an electrical heater is installed inside the chamber and operated under steady state conditions. The rate at which heat is delivered to the interior of the chamber is then equal to the measured rate at which electrical energy is supplied to the heater. The blower which draws air slowly through the chamber is operated at various speeds, and the inlet to outlet temperature rise is recorded. Plots of these measurements, as shown in Figure 4, constitute a calibration of the calorimeter system.

Figure 5 shows the inlet to outlet temperature difference during and after the charging process for an actual test of a 2kW TES unit which is now on the market. Since the internal blower within this unit was not operated during the test the results indicate heat losses during charging and standby. Initially the unit was at room temperature, but as electrical energy was supplied its internal temperatures rose, and heat transfer from the unit to the air inside the chamber increased as indicated by the inlet to outlet air temperature difference. After 8 hours of charging the electrical input was terminated, and the rate of heat loss from the unit to the air gradually decreased.

Figure 1. Central TES Unit (Foreground) and Calorimeter Chamber for Testing of Room-Size TES Units

Figure 2. View of Calorimeter Chamber from Opposite Side

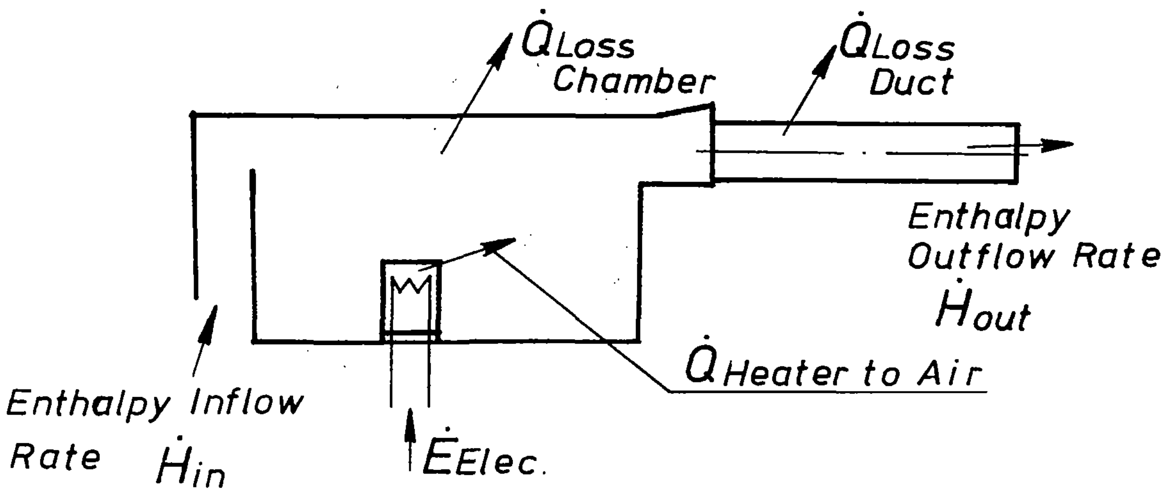

Figure 3. Schematic Diagram of the Essential Features of the Calorimeter Chamber Illustrating the Various Energy Flow Rates

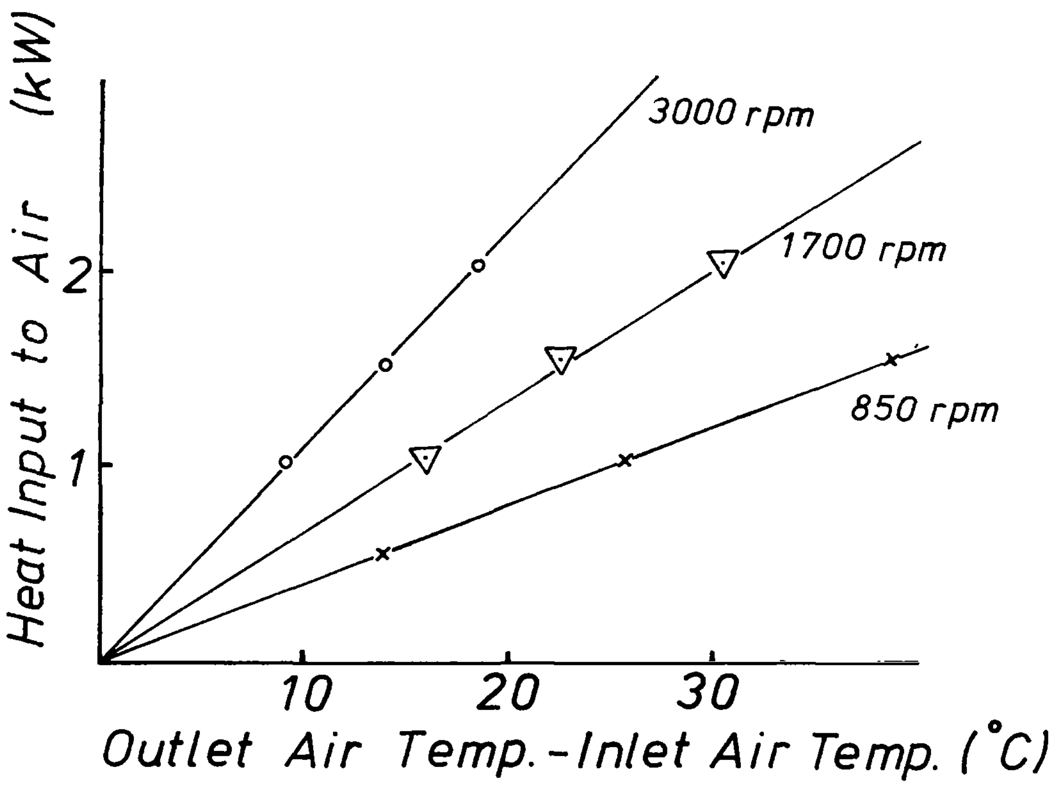

Figure 4. Calibration Chart Obtained Under Steady State Conditions with Calorimeter Blower Speed as Parameter

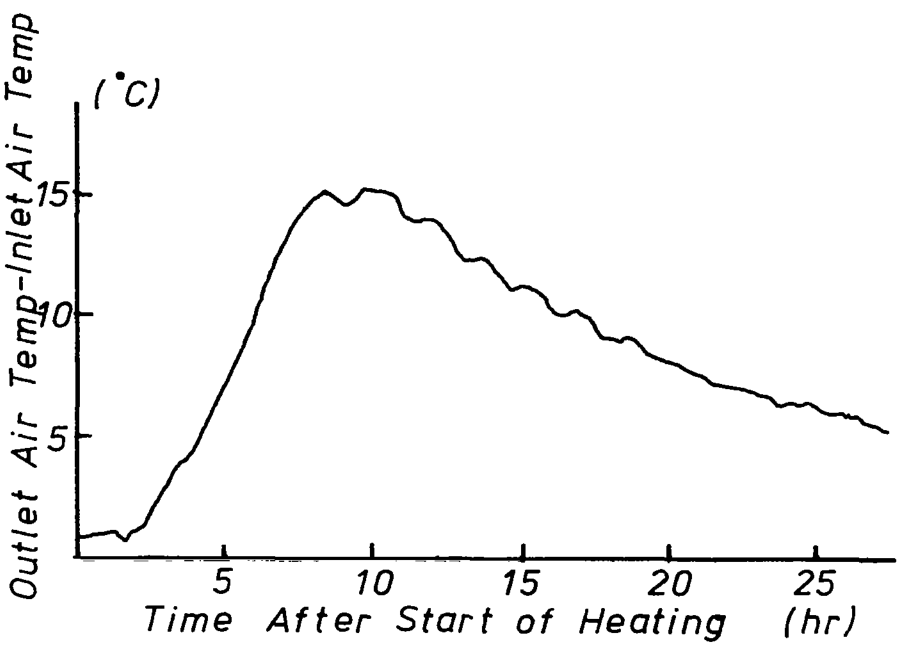

Figure 5. Measured Inlet to Outlet Temperature Difference During and After an 8 Hour Charging Period for a 2KW TES Unit (Calorimeter Blower Speed = 850 rpm)

For any instant of time the temperature difference from Figure 5 can be used with the calibration chart in Figure 4 to determine the rate at which the heating unit under test delivered heat to the air inside the calorimeter. This procedure provides correct results under the following assumptions:

1. The net enthalpy outflow rate for the air, as indicated by the measured temperature difference during the test, is the same as that occuring during the calibration test at the same measured temperature difference.
2. The heat loss from the calorimeter system to the surroundings during the test is the same as that occuring during the calibration test at the same measured temperature difference.
3. The rate of change of internal energy of the chamber and the air contained inside is negligible during the test.

The procedure indicated above is very desirable because of its simplicity. However, the assumptions listed raise questions about the validity and accuracy of the results obtained. Therefore, these aspects are being evaluated during the course of this project.

In regard to assumption 1 it should be pointed out that typically there are air temperature variations over the outlet duct cross-section. Because of this a thermopile, consisting of 20 pairs of thermocouples connected in series, is employed with alternate junctions placed in the inlet duct and outlet duct, respectively. The inlet duct has a rectangular cross-section and the outlet duct has a round cross-section. Locations of the thermocouples in the ducts are indicated in Figure 6, (a) and (b). Figure 6 (c) illustrates the series arrange-

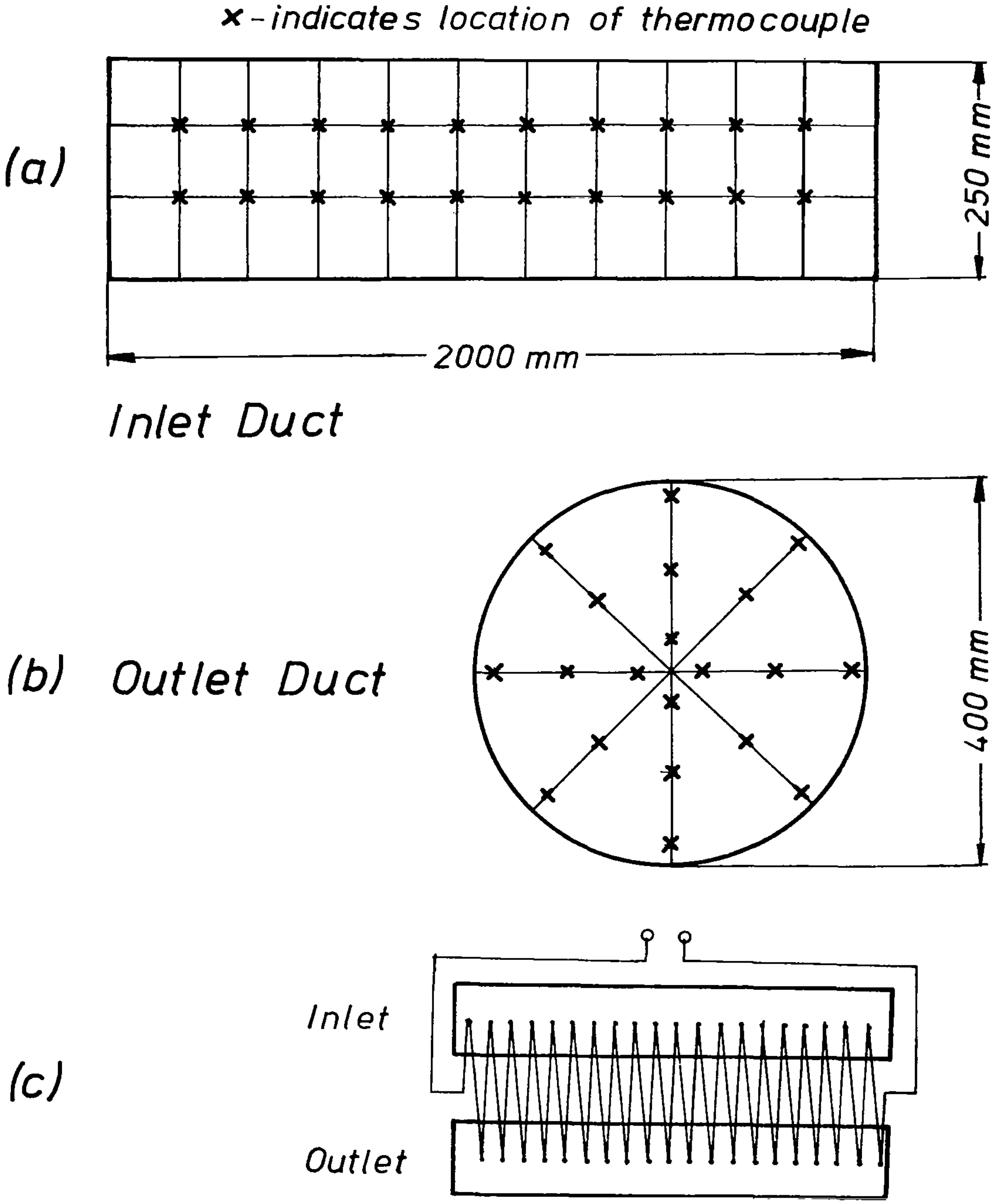

Figure 6. Thermocouple Arrangement: (a) Inlet Duct, (b) Outlet Duct, and (c) Thermopile Formed by Series Arrangement of Thermocouples

ment of the thermocouple pairs. With this procedure the voltage output indicates essentially the difference between the average inlet and average outlet air temperatures (averages taken over the duct cross-sections).

On a rigorous basis the enthalpy flow rate for the outlet air is indicated by the mixed mean temperature, which depends upon the temperature profile and the velocity profile in the outlet duct. The velocity profile is unknown, unless very detailed velocity measurements are made within the duct to determine it. In general the mixed mean temperature is not equal to the average temperature, but these two temperatures approach each other as the air temperature over the cross-section becomes more uniform, no matter what the velocity profile may be. The room air entering the calorimeter has a uniform temperature, so this condition is achieved in the inlet duct. However, initial operation of the chamber revealed sizable temperature variations within the air in the outlet duct. Temperature variations within the outlet duct cross-section as high as 53% of the average inlet to outlet temperature difference were detected by means of individual thermocouples placed at the locations of the thermopile thermocouples. The air in the chamber and in the duct apparently stratifies due to buoyancy, and the warmer and cooler portions of the air tend to remain separated as they move through the outlet duct. Under these conditions the measured average inlet to outlet temperature difference is not guaranteed to represent the net enthalpy flow rate accurately, because of the possible deviation between the average and mixed mean outlet temperatures. Hence, such measurements are not considered acceptable.

In order to obtain a more nearly uniform outlet air temperature baffles were installed in the chamber in an attempt to create a more uniform temperature for the air entering the outlet duct. This produced a small improvement. Mixing louvers placed at the entrance to the outlet duct unfortunately were found to produce no improvement. However, a more carefully designed set of mixing louvers was installed further downstream in the duct, and the duct was lengthened to allow a greater distance for mixing. The 53% difference referred to above was reduced to only 5% with this re-designed system, at the same heating rate and air flow rate. The deviation between the average and mixed mean outlet temperatures is estimated to be only about 1% of the average inlet to outlet temperature difference. This is considered quite satisfactory, but work is continuing on this problem to see if the present arrangement will be effective over the ranges of heating rate and flow rate to be encountered.

FUTURE WORK

Efforts will continue to be devoted to reducing inaccuracies and verifying the test procedures and apparatus being developed. Commercially available room-size units of different sizes are being tested, and the calorimeter chamber system and the associated test procedures will be refined as this experience is accumulated. Testing of central units will proceed simultaneously, first in a conventional laboratory environment and eventually in an environmentally controlled chamber in order to determine how significant the ambient air temperature is in affecting the test results. If test results are found to be not very sensitive to the ambient air temperature, a severe specification for the ambient air temperature can be avoided in the eventual recommended standard test procedure for these units.