An Identification Technique
for Transient Heat Flow through Walls

Fariborz Haghighat Hong Liang
Centre for Building Studies
Concordia University,
Montreal, H3G 1M8

ABSTRACT

The paper is concerning the determination of dynamic thermal response of walls by applying system identification techniques. It is proposed to follow the following steps: select the form of the model; devise a test apparatus capable of maintaining the boundary conditions and measuring input and output variables; excite with an input signal; fit the model parameters to the measured data. A Binary Multi-Frequency Sequence signal was used for identification purpose.

INTRODUCTION

Knowledge of the dynamic response of building envelopes is required for HVAC system design and thermal comfort study. American Society of Heating Refrigerating Air-conditioning Engineers (ASHRAE) has adopted the z-transfer function method to calculate the transient heat conduction through building envelopes. Z-transfer function coefficients for 179 different construction types are listed in the ASHRAE Handbook[1]. Analytical techniques to predict the performance characteristics of a building envelope from material properties do exist. These, however, rely on assumptions (such as air film coefficients) and are not sufficiently reliable for use in control algorithms.

A complete dynamic model for the heat flow through a wall is commonly represented in the matrix notation introduced by Pipes[2], which relates the temperatures and heat flows at both surfaces:

$$\begin{bmatrix} Q_o \\ Q_i \end{bmatrix} = \begin{bmatrix} \frac{D}{B} & -\frac{1}{B} \\ \frac{1}{B} & -\frac{A}{B} \end{bmatrix} \begin{bmatrix} \theta_o \\ \theta_i \end{bmatrix} \qquad (1)$$

As an example, the transfer function 1/B relates the heat flow through the inside surface to the temperature at the outside surface. This transfer function in z-domain can be expressed as a ratio of two polynomials in z^{-1}:

$$H(z) = \frac{1}{B}(z) = \frac{a_0 + a_1 z^{-1} + a_2 z^{-2} + \ldots + a_n z^{-n}}{1 + b_1 z^{-1} + b_2 z^{-2} + \ldots + b_m z^{-m}} \qquad (2)$$

Where a and b are z-transfer function coefficients to be determined.

DESCRIPTION OF TEST PROCEDURE

From Equation 1, the definition of transfer function 1/B is:

$$\frac{1}{B(z)} = \frac{Q_i}{\theta}\bigg|_{\theta_i = const} \qquad (3)$$

Where, $\theta = \theta_o - \theta_i$. The experimental requirement to obtain the frequency response of 1/B are: 1) to maintain the temperature θ_i constant; 2) to vary the temperature θ_o; and 3) to measure the heat flux Q_i.

To meet the test requirements above, the test apparatus was set up as shown in Figure 1. Three electric heaters were used. Heater H_1 was controlled to maintain temperature θ_i to be constant. Heater $H_{2,a}$ and heater $H_{2,b}$ were switched on and off, with input signal, to produce a varying temperature θ_o. Two cold plates served as the sink for the heat from the heaters. The two samples have the same thermal properties and thickness.

Using this symmetrical configuration, the heat flux Q_i can be determined from the measurement of the power supplied to the heater H_1. Since the system is symmetrical, half of heat flow will be transferred to each side of the system. Heaters $H_{2,a}$ and $H_{2,b}$ were turned on and off using a Binary Multi-Frequency Sequence (BMFS) signal obtained from the equation [3]:

$$G(t) = \cos(wt) - \cos(2wt) + \cos(4wt) - \cos(8wt) + \cos(16wt) - \cos(32wt) + \cos(64wt) \qquad (4)$$

where, $w = 2\pi/P$, where P is period of the sequence. Heaters $H_{2,a}$ and $H_{2,b}$ were turned on when $G(t) \geq o$ and, off when $G(t) < o$.

Figure 2 shows the input and output signals for derivation of 1/B. The input signal is the temperature drop across the surface. The output signal is the heat flux determined from the power applied to the heater. The frequency response of the transfer function was obtained from equation (3) by performing a Fast Fourier Transform on the input and output signals. The z-transfer function coefficients were obtained by applying a multi-linear regression computation to fit z-transfer function coefficients to the frequency response[4]. Figure 3 shows the measured and fitted frequency response, compared with the theoretical calculated response[4].

CONCLUSION

A procedure has been developed to experimentally determine the transient heat transmission transfer function for a wall specimen. The predicted frequency response agreed fairly good with the measured value.

A binary multi-frequency sequence was used as the input excitation θ_o. This type of signal has several attractive characteristics for system identification. It is easy to produce, requiring no complex wareform generator or precise control. The technique could be applied for the determination of the dynamic characteristics of other elements such as HVAC systems components.

REFERENCES

1. ASHRAE, "ASHRAE Handbook-1977 Fundamentals", Chapter 26, Inc. 1977.

2. Pipes, L. A., "Matrix analysis of heat transfer problem", Franklin Ins. Journal, 1957.

3. Van der Bos, A., "Construction of Binary Multi-Frequency Signals", IFAC Symp. 1967.

4. Haghighat, F. and D.M. Sander, "Experimental Procedures for Determination of Dynamic Response Using System Identification Techniques", Journal Thermal Insulation, Vol. 11, pp.120-143, 1987.

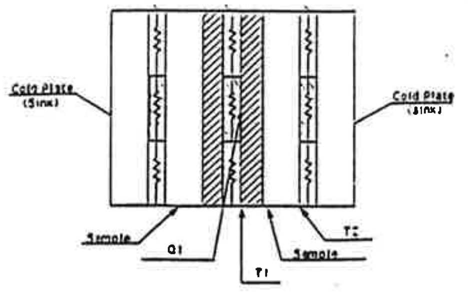

Figure 1 Schematic of Test Apparatus

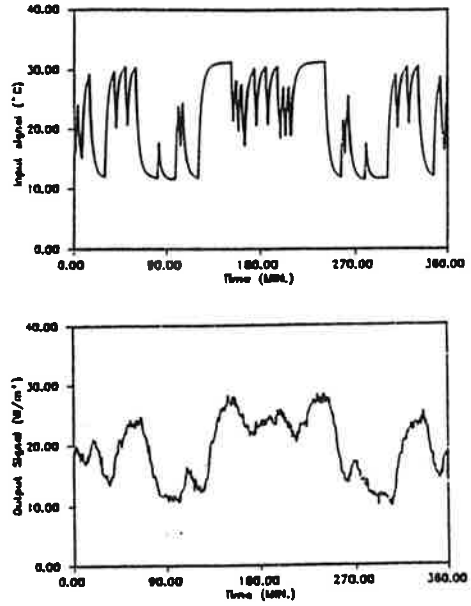

Figure 2 Input and output signals for 1/B

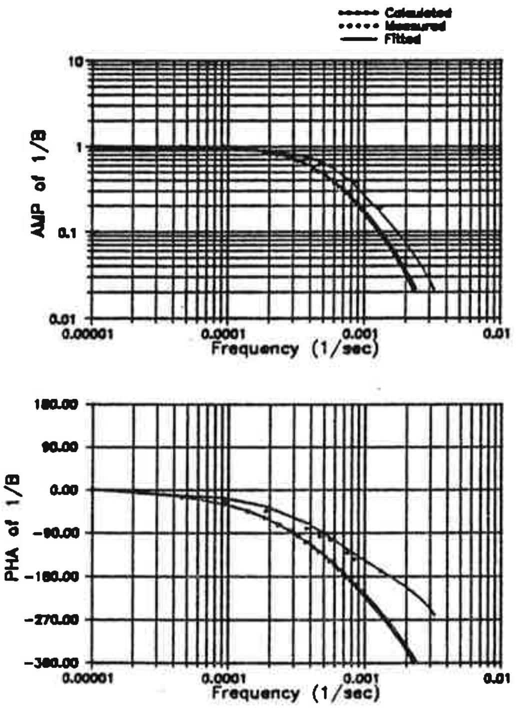

Figure 3 Frequency response of transfer function 1/B. The coefficients are: a0=0.000, a1=0.017, a2=0.062, a3=0.045, b1=-1.250, b2=0.375, and Δ=2 min.