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Air Movement in a Re-clad Medium Rise Building and its Effect on Energy Usage

H G Kula*, I C Ward**

* Lawrence Berkeley Laboratory, Energy Performance of Buildings, Bldg 90, Room 3074, Berkeley, CA 94720, USA

** Building Science Research Unit, School of Architectural Studies, The University of Sheffield, P O Box 595, The Arts Tower, Sheffield, United Kingdom

ABSTRACT

This paper presents the results of a monitoring programme on a medium sized educational building which has had the external walls re-clad. The objective behind the re-cladding was to improve the durability of the building and to improve the thermal performance.

The objectives of this work were to establish the viability of the calculation techniques used to simulate the ventilation, thermal and moisture performance of the re-cladding system.

The results have shown that there is a good agreement between the methods currently being used and the actual performance.

1. BACKGROUND

As part of the upgrading policy of the University of Sheffield the external facade of a nine story office building has been re-clad with a ventilated cavity wall structure which includes thermal insulation and weep hole devices to remove any moisture build-up.
As this type of re-cladding system is not common in such large buildings it was felt necessary to investigate its performance with a view to establishing the viability of the current techniques for estimating the performance of structures. In order to do so an extensive programme of both physical and computer modelling was carried out.

1.1 The Wall Construction

The external wall of the building originally consisted of exposed concrete floor slabs with a GRP infill panels. In order to minimise the cold bridging effect of such a construction the re-cladding consisted of attaching to each slab an angled beam onto which was built a brick outer layer. Because of the exposure of the building it was felt that weep holes should be left in the wall to allow any moisture which may build up to escape. However these holes will also allow air to enter and therefore there may be a reduction in the insulating properties of the structure. Figure 1 shows a cross section of the re-clad wall.

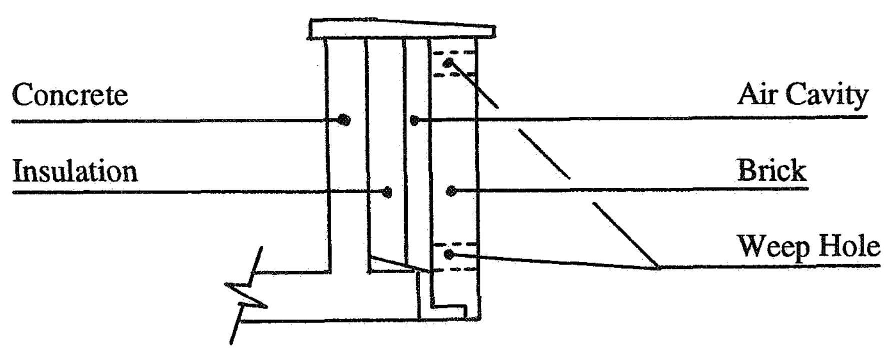

Figure 1: Construction of External Wall

2. LABORATORY MEASUREMENTS

2.1 Ventilation performance of the Wall Construction

This series of experiments concentrated on establishing the air flows within the cavity between the outer brickwork and the thermal insulation. Most of the results of this programme were presented at the an earlier AIVC Conference(1) and indicated that it was possible to measure the air flow into an air cavity 1.2 metres high and 46 meters long. The measurements presented were then used in the COMIS simulation programme to carry out a study into the cavity performance under various wind conditions. The wind conditions simulated were based on measurements taken at the local Meteorological Station. In order to carry out the simulations it was necessary to obtain reliable values of the wind pressure coefficients acting on the building.

2.1.1 Wind Tunnel Testing

The building including the immediate surroundings were simulated in a boundary layer wind tunnel to establish the Cp values acting on the facades of the building. A full report on this work is available from the School of Architectural Studies(2).
Table 1 shows for the four main facades the difference in Cp values obtained by simulation with and without surrounding buildings.

Table 1: Cp Values for the Office Simulated		
Orientation	Isolated	Within Surroundings
North	-0.117	-0.031
North East	-0.203	-0.137
East	-0.142	-0.138
South East	-0.193	-0.129
South	0.14	0.02
South West	0.196	0.161
West	0.199	0.144
North West	0.065	0.152

2.2 Insulation material and humidity

2.2.1 Introduction

Previous work by Burch et al. (1989)(3) and McLean et al. (1990) (4) suggested that the vapour permeability of building materials is not affected significantly by the prevailing ambient temperature, and for effectively non-hygroscopic materials, such as plasterboard and polystyrene, the permeability is essentially independent of humidity. For calculations of these materials a constant value can be assumed, causing little error. However, for hygroscopic materials, such as wood, plywood and brick the permeability depends substantially on the ambient humidity and may vary significantly. To minimise errors in calculations for these materials the vapour permeability should be taken into account.

2.2.2 Moisture absorption

Table 2 shows the results of the laboratory investigations. Very little vapour was absorbed by the insulation material.

Table 2: Various test conditions during the experiment

day, time		box		laboratory	
-	weight	temperature	humidity	temperature	humidity
-	[g]	[°C]	[%]	[°C]	[%]
dry sample	35.464	-	-	-	-
1, 10:40	35.555	22.1	76.9	22.3	27.1
1, 11:40	35.555	21.8	92.8	21.6	28.5
2, 11:20	35.568	22.0	94.5	22.1	31.4
3, 13:30	35.561	19.9	98.5	21.6	39.3
4, 11:00	35.563	19.6	99.3	20.4	49.4

The test has shown that the insulation material is non-hygroscopic, a negligibly small amount of moisture was accumulated in the insulation material.

2.2 3 Tests for Hygroscopy

A specimen of 0.2 x 0.1 m was submerged in a water bath. After 44 hours the specimen was cut up into four parts and no capillary diffusion could be detected.

3. FIELD MEASUREMENTS

A full monitoring programme of measurements in one office in the building was set up and continued for one year. Figures 2 and 3 indicate the type of results obtained.

The long-term data collected was used to establish the following:

- the time constant of the wall structure
- the dynamic u-value of the ventilated wall structure
- the influence of the wind on the temperature stratification in the cavity
- the ventilation simulation with COMIS, and
- the thermal simulation with SPARK.

3.1 Time constant of the wall structure

With the measured weather data, the temperatures in the wall and the room temperature, it was possible to determine the time constant of the wall structure. The average time lag of this wall structure was calculated to be 6 hours and 15 minutes. The analysed data is presented in Table 3. The value for the time constant for this type of structure taken from Table A3.17 in the CIBSE Guide (A3) ranges between 8 and 9 hours.

Table 3: Time lag of the wall structure during 23.3 - 26.3.1993

t_{out} max °C	time of day hrs:min	t_{in} max °C	time of day hrs:min	time lag hrs:min
9.4	10:10	19.7	16:20	6:10
10.6	10:44	20.3	18:15	7:31
15.3	11:38	19.2	17:38	6:00
13.8	10:31	21.6	15:51	5:20
			average time lag	6:15

The problems encountered in the determination of the time constant of this structure using the measured data were the following:

1. Heat sources in the room,
2. The unknown occupancy of the room,
3. Workmanship

3.2 The dynamic u-value of a ventilated cavity wall

To estimate the dynamic u-value the model developed by Anderson(5) has been used. Solving Anderson's model for a given time period results in the average heat transmission rate incorporating the dynamic behaviour of the wall being estimated. Tests carried out by Anderson et al. (1985) show that the u-value can be estimated within an accuracy of 10 % provided the following conditions are met,

(a) the indoor outdoor temperature difference is at least 20 K,
(b) the daily outdoor temperature swing (high to low) is not larger than half the average indoor outdoor temperature difference,
(c) the average indoor and average outdoor temperatures do not vary significantly over the course of the test, and

The results of the calculations for several months are presented in Table 4 along with the calculated values from recognised design manuals.

Table 4: Comparison of the calculated and standard u-values			
	measured (Anderson) W/m^2 K	calculated u-value W/m^2 K	CIBSE / measured %
February	0.46	--	0
March	0.39	--	- 15.2
April	0.48	--	+ 4.3
May	0.43	--	- 6.5
June	0.54	--	+ 17.4
average	**0.46**		
CIBSE Guide	--	0.43 - **0.46** - 0.49	0
DIN 4701	--	0.494	
ASHRAE	--	0.51 - 0.52	

The results of the integrated u-value calculations show, with the exception of the June and March u-values, good agreement with the u-values calculated using the various standards. The difference between the calculated u-value using the measured data and the averaged CIBSE Guide value is also stated.

3.3 Effect of Wind Speed on Cavity Air Temperature.

A hypothesis that high wind speeds would destroy air stratification in the ventilated cavity was investigated. Although initial results indicated that there was some evidence for this a detailed study of the cavity air temperatures, wind speed/ direction, solar radiation and outside air temperature did not substantiate this hypothesis.

3.4 Analysis of the COMIS simulation results

Considering that the computer simulations were carried out using constant "set" temperatures for the cavity air, the outside air and the crack temperature, as well as the wind direction and wind speed the results from the simulation with the COMIS programme and the measurements on the cavity structure in the Building compare reasonably well. Table 5 summarises the results of the simulations and measurements carried out.

Table 5: Simulated and measured results				
test	wind direction flow direction	wind velocity m/s	COMIS [m^3/s]	measured [m^3/s]
1	340 north - south	2.5 measured	0.001645	0.00165
2	200 - 210 south - north	4.1 measured	0.00262	0.0029
3	280 north - south	5.6 measured	0.00473	0.0048
4	240 south - north	5.6 - 12.3 MET Office	0.00532 - 0.01167	0.00771
5	270 south - north	5.7 - 12.4 MET Office	0.00127 - 0.00379	0.00145
6	260 south - north	6.2 - 11.8 MET Office	0.00165 - 0.00351	0.00233

3.4 Analysis of the SPARK results

For the SPARK simulation five chosen data sets of representative weather were considered giving a large number of results to be analysed. The approach adopted was to compare the heat flux through the inside of the wall, the insulation temperature and the measured temperature between the insulation material and the concrete. Figures 4 and 5 show typical output from the analysis.
The comparison of the simulated and the measured data for the thermal simulation with SPARK showed good agreement for the insulation temperature. This result could not be produced for the simulation of the inside wall heat flux. Although the correlation between the measured and the simulated heat flux can be described as satisfactory the absolute values for peak heat flow through the wall, especially during high solar radiation, is very poor. The overall conclusion drawn for the SPARK simulation is that the program as it stands cannot handle the inside heat flux. The main limitation of the SPARK program was that it calculated the one-dimensional heat flow through the opaque part of the wall only, disregarding the complex three-dimensional heat flow processes taking place not only through the opaque part of the wall, but also through the window, which was not simulated.

4. CONCLUSIONS

The thesis from which this paper has been written was concerned with experimental and theoretical studies of the thermal and ventilation performance of a retrofitted ventilated cavity wall.

The main objectives were:

i) **Moisture Performance**
- To test if the insulation would absorb moisture.

ii) **Thermal performance**
- To determine how the wall structure performs, thermally, and to derive the dynamic u-value of the structure.

iii) **Ventilation performance**
- To test if the ventilation of the cavity works.
- To see if the air flow in the cavity can be measured.

iv) **Computer modelling**
- To compare the measured and the modelled values for the thermal performance of the wall structure, in order to assess the wall performance in practice.

i) Moisture performance

Concluding it can be stated that the experiments carried out to determine the effect of moisture on the insulation material in the cavity have shown that the effects were insignificant

ii) Thermal performance

By setting up a long-term monitoring system collecting temperature data throughout the wall structure, measuring the inside heat flux and collecting relevant weather data, it was possible to calculate the dynamic u-value of the wall. Data for five test periods, chosen for their distinctive features, were analysed. The calculated averaged dynamic u-value agreed well with the steady state calculation according to three design guidelines, CIBSE A3, DIN 4701 and ASHRAE, which do not take account of weep holes. The agreement of the averaged dynamic u-value for the five test periods with the CIBSE A3 Guide was within ± 7%.

ii) Ventilation performance

The results of the measurements indicate that horizontal air flow in the cavity occurs, and is mainly dependent on the pressure forces around the building due to the wind. For high wind speed, with wind direction being windward for the cavity under investigation, flows of up to 0.0071 m^3/s were measured. For a lower wind speed of up to 2.5 m/s the flow was determined to be 0.00165 m^3/s.

iii) Computer modelling

a) COMIS

For this part of the investigation two approaches were adopted - the tests carried out under laboratory conditions, and the in-situ measurements. The laboratory test were mainly carried out to test and validate the tracer gas technique developed to measure the in-situ air flow in the cavity. It was found that the uncertainty involved in the technique was within ±7%.

The overall conclusion for the ventilation simulation using the COMIS program package was that the results agreed very well with the measured data.

b) SPARK

The comparison of the SPARK simulation results and the measured performance of the wall achieved unsatisfactory agreement. The correlation between the two sets of data ranges from 0.599 to 0.933. However, the comparison of the simulated and the measured data for the insulation temperature showed good agreement. Although the correlation between the measured and the simulated heat flux on the inside wall can be described as satisfactory the absolute values for peak heat flow through the wall, especially during high solar radiation, is very poor.

An explanation for sometimes low correlation value lies in the different situations measured and modelled. The main limitation for the modelling was that the in-situ measurements take the complex three-dimensional heat flow into account, whereas the simulation was carried out for one-dimensional heat flow only.

From the results for the thermal simulation with SPARK it is concluded that the program does not model the situation very well.

5. REFERENCES

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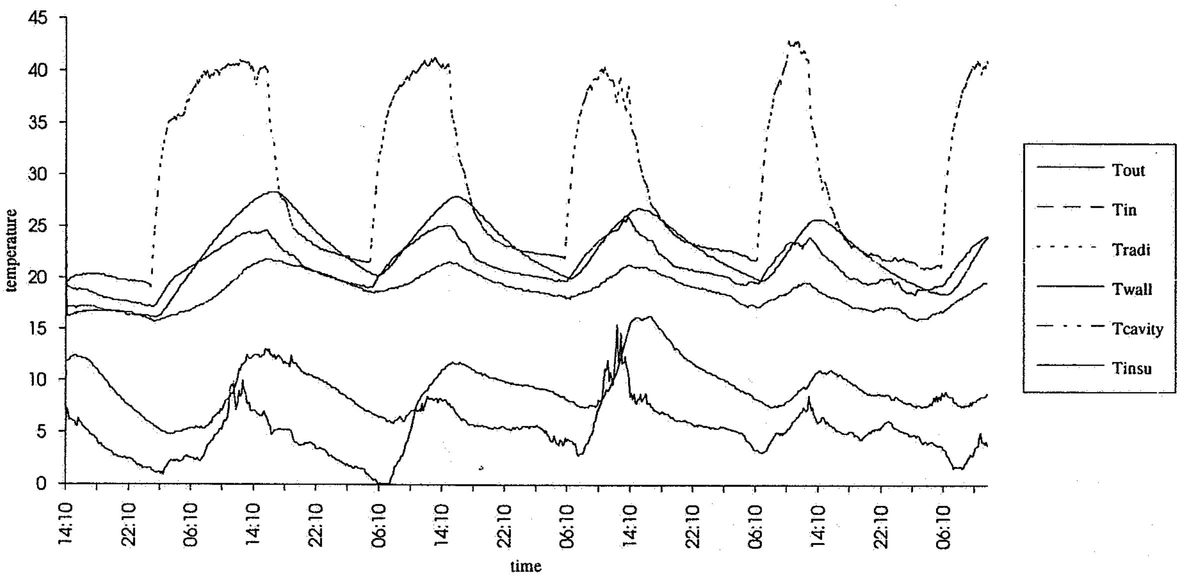

Figure 2: Measured Inside Wall Heat Flux for February

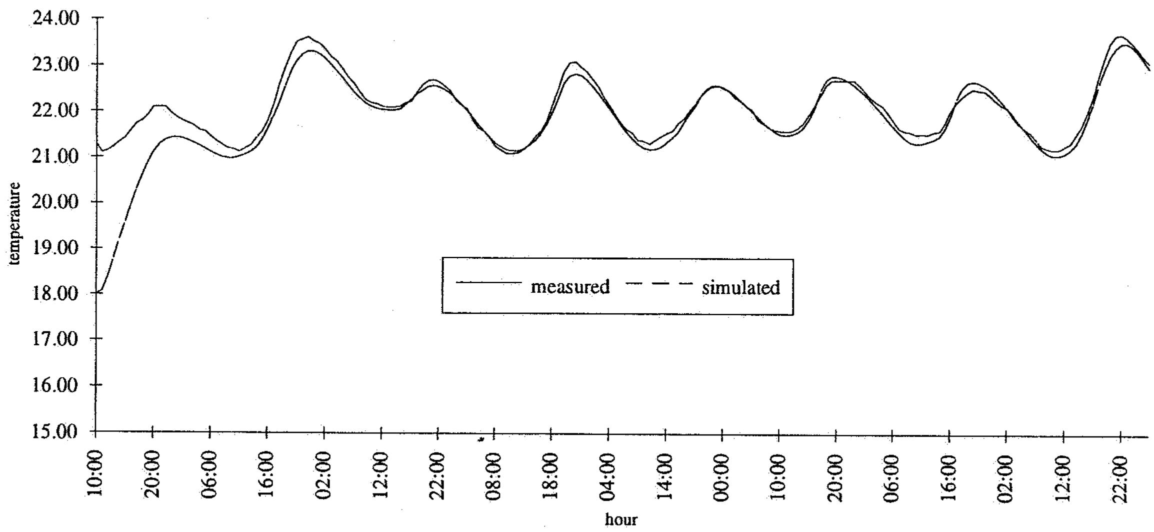

Figure 3: Comparison of the Measured and Simulated Insulation Temperature in June

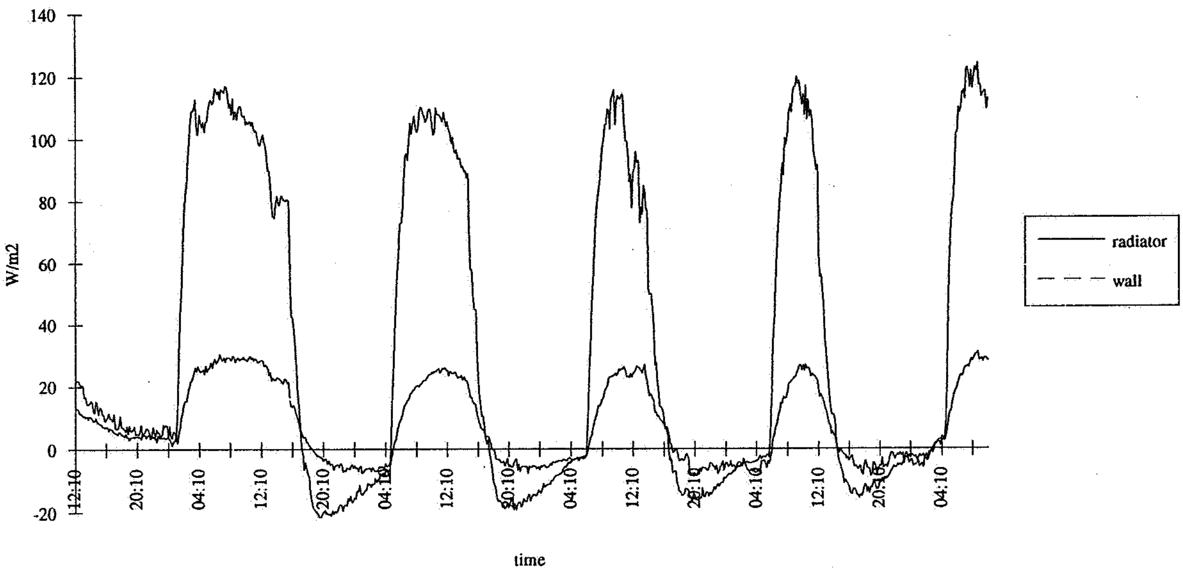

Figure 4: Measured Inside Wall Heat flux for February

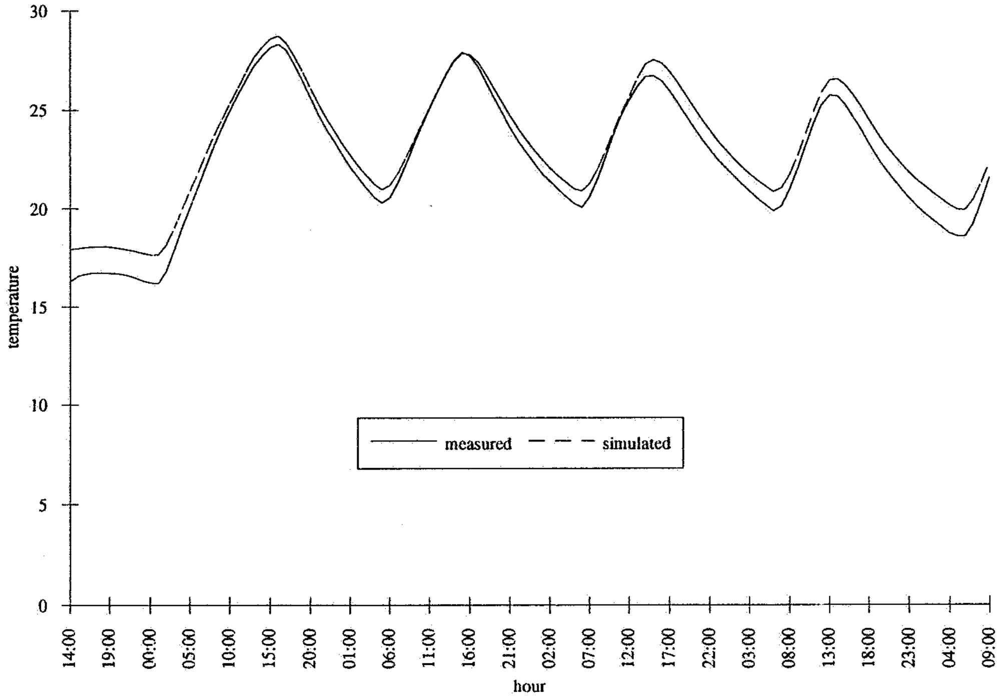

Figure 5: Comparison of Measured and Simulated Insulation Temperature in February