TREATING THE CAUSE - NOT THE SYMPTOMS!

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Finding a solution to the problem of draughty buildings can be fraught with difficulty. Very often only the symptoms are apparent and the root cause can be difficult to identify. All too often a 'try and see' approach is adopted until finally, if luck prevails, a successful solution is found. The design team addressing the problem of a draughty mall at a shopping centre in Shrewsbury adopted a different approach. The possible causes were identified using site knowledge and Computational Fluid Dynamics. A 'blind' analysis of site data was then undertaken by an independent statistician ie. the statistician was not told the possible causes identified by the design team. The statistical analysis of the site data confirmed the views of the design team and the appropriate solution was implemented.

INTRODUCTION

A well-established shopping centre in Shrewsbury had been connected to a newly-developed shopping centre via a Link Mall in order to allow shoppers access to both complexes in relative comfort. Both centres were covered, although only the new centre was heated.

Symptoms of the Problem

Both retailers and shoppers complained that, during the winter months, the Link Mall was subject to excessive draughts and neighbouring retail units were always cold and inhospitable. The problem area is identified on the schematic Plan and Section which are shown in Figure 1.

Suggested Remedy

There had been several attempts to resolve the problem. It had been suggested that an enclosed lobby be created at the entrance to the Link Mall to impede air flow. The obvious disadvantage of this suggested strategy is that it would defeat the objective of integrating the two shopping centres into a single entity. Furthermore, additional doors and lobbies were not considered "customer-friendly" and would inhibit customer traffic between the shopping centres. Even if these measures were taken, would the problem be cured?

Identifying the Cause

The explicit brief to Building Simulation was to undertake a computer simulation of the proposed solution using Computational Fluid Dynamics (CFD). However, after a site visit and some basic site air velocity measurements, the proposed solution just did not "feel" right. It was also noted that the shopping centres were very busy and the entrance doors, even in a lobby arrangement, would be almost permanently open. The hill entrance was not in an exposed location and it was sheltered from the prevailing wind. Furthermore, the excessive air velocities in the Link Mall appeared to occur when either the Rousehill or South Mall entrances were opened. It was suspected that the cause of the problem was not necessarily wind driven. It was decided to use the computer CFD model to test whether the team's theories about the cause of the problem could be right rather then testing one solution via the model.

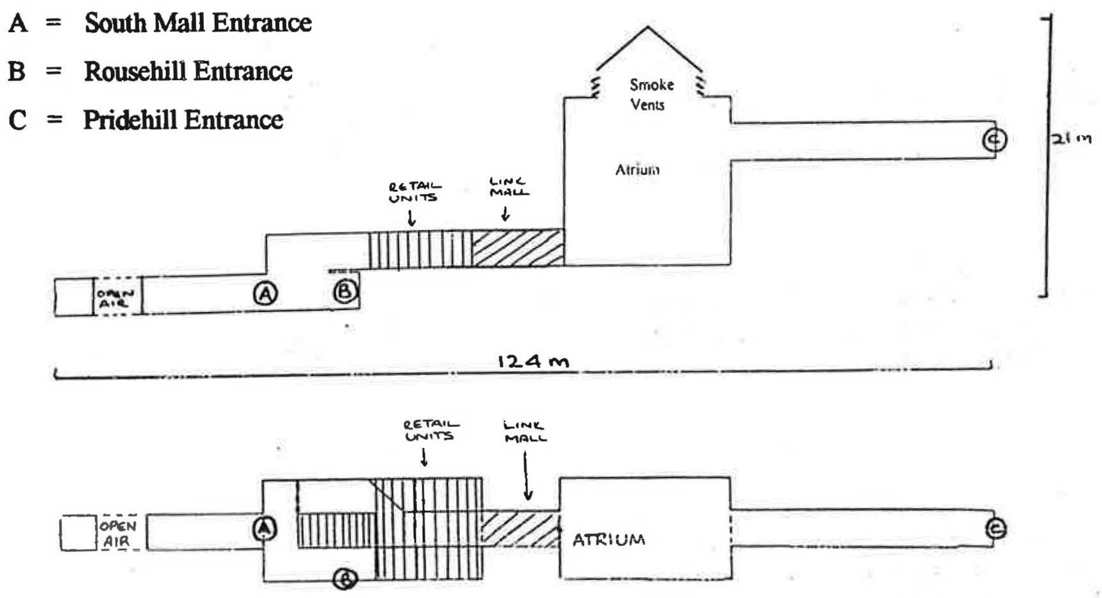

Figure 1 Section and plan of the Shrewsbury shopping centres (not to scale)

The CFD model was run for a number of scenarios in an attempt to recreate the conditions observed in the Link Mall. It became apparent that the conditions in the Link Mall could only be recreated in the CFD model when either:

i) excessive wind pressure was applied to the Rousehill or South Mall entrance, or

ii) the atrium was not assumed to be air tight and therefore allowed to 'leak'.

The simulations undertaken on the CFD model did not suggest that it was the internal geometry of the shopping centre which was causing the problem, but the design team kept an open mind and the possibility was not discounted.

The client and the client's property manager were confident that the atrium was air tight (a confusion perhaps with water tight?). The design team on the other hand felt that a leak atrium was the more likely cause. In essence, the team had now identified three possible causes and three potential remedies as shown in Table 1.

Table 1: Possible causes and corresponding remedies

Possible Cause	Suggested Remedy
Wind-driven air flow due to the orientation of the Rousehill Entrance	Offset lobby
Suction effect due to the internal geometry of the Atrium	Additional lobbies and doors
Suction-driven air flow due to leakage from the Atrium roof	Make Atrium roof airtight

Having three possible entrances into the centre meant that there were eight possible combinations of open/closed configurations. Each entrance has a different orientation and hence is subject to different wind pressures. Furthermore, there are smoke vents in the Atrium roof which were operated largely in an *ad-hoc* manner to induce air movement for ventilation and cooling during the summer. However, during the winter when the draughty Link Mall becomes inhospitable, these vents are kept closed.

It would have been expensive (both in time and resources) to have investigated all possible scenarios using computer modelling techniques; in fact, it would have been virtually impossible. Additional constraints were placed on the design team, in that the solution needed to be identified on a tight budget – and quickly. Therefore, the rather unconventional decision was taken to apply statistical analysis to site-collected data. This decision proved critical in reaching a solution within the client's declared budget and time scale.

Site-collected Data

The design team suspected that suction-driven air movement could be caused by air leakage from the (closed) smoke vents located in the Atrium roof. Consequently, a number of data loggers were set up at strategic locations and synchronised to monitor air velocity over time (see Figure 2). The six selected locations for the data loggers represent the minimum number necessary in this situation to provide global wind-velocity information for analysis. The primary dependent variable (effect) is monitored within the Link Mall itself, and the remaining variables are explanatory (possible causes).

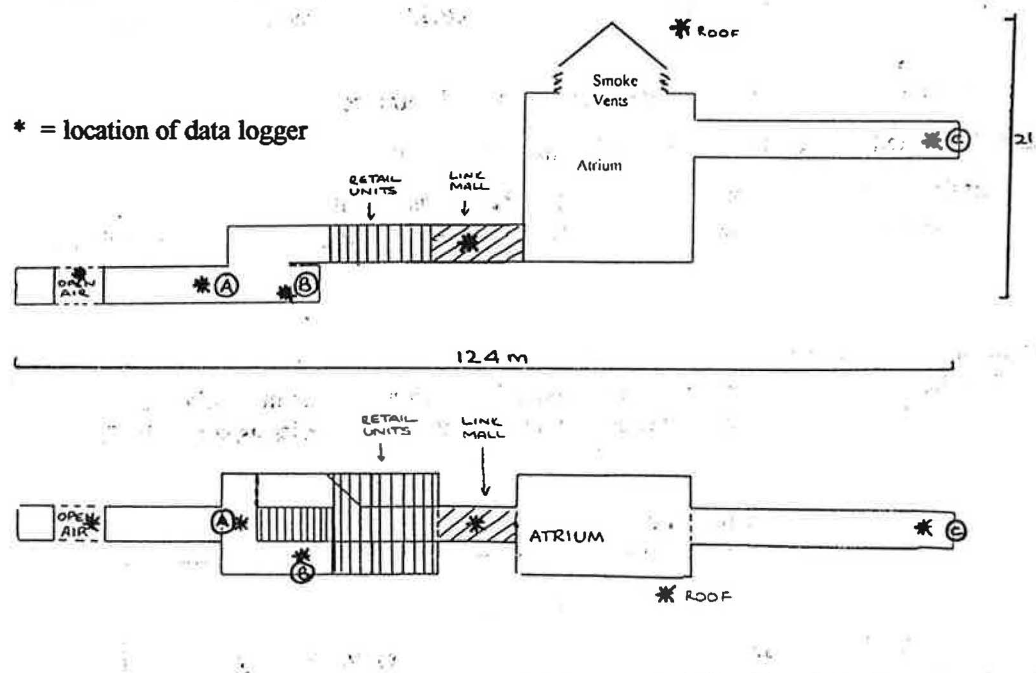

Figure 2 Section and plan of shopping centres showing locations of data loggers

The open/closed door configurations were then crossed with three smoke Vent states; namely open, closed and taped. This design could generate (8 x 3 =) 24 sampling environments. The monitoring of air flow whilst the smoke vents were taped was an essential step to confirm the integrity of the vents, which were suspected of air leakage even when closed. The final stage of this exercise, when the smoke vents were taped, was conducted in a state of high security with a Fire Officer present as an additional precaution. The logged air-flow data from these tests were downloaded and combined with binary/tertiary representations of the door/vent configurations and sent for independent statistical analysis.

Statistical Analysis

Preliminary analysis using the concept of correlation between the observations obtained for each of the 15 possible pairs of variables, identified an obvious association between the wind speeds recorded on the roof and the ground (see Table 2). However, the air flow in the Link Mall was found to be significantly correlated with only two of the three entrances. The doors located at the Pridehill Entrance were found to have virtually no influence on the adverse conditions within the Link Mall, or indeed any of the other variables considered.

Table 2: Pearson cross-product correlation coefficients

	Pridehill	Rousehill	South Mall	Roof	Ground	Link Mall
Pridehill	–	0·182	–0·033	0·140	0·131	–0·121
Rousehill		–	–0·118	–0·008	–0·021	0·682***
South Mall			–	0·002	0·195	0·546**
Roof				–	0·780***	–0·011
Ground					–	0·086
Link Mall						–

*, **, *** denote significance at 5%, 1%, 0·1% levels.

A possible "causality" diagram may be constructed as shown in Figure 3. The isolation of the (bonded) roof-ground air velocities immediately suggests that the problem is not wind driven. The second-ranking coefficient between logged data at the Rousehill Entrance and the Link Mall indicates a preferred route for satisfying demand in the Atrium; and the South Mall Entrance is implicated as an alternative (but subordinate) route. These significant correlation coefficients were explored further.

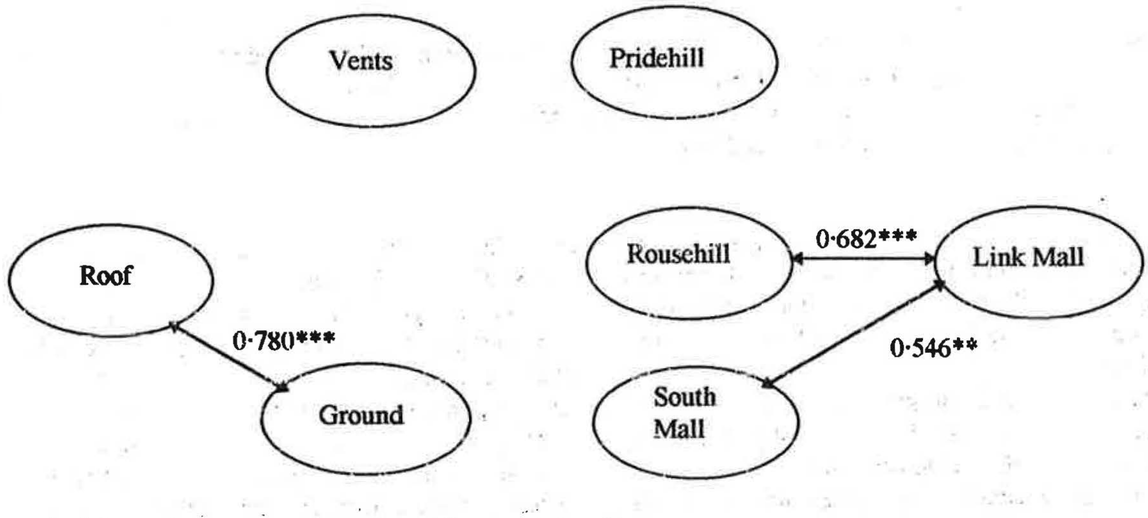

Figure 3 Schematic representation of significant relationships

Regression analysis was performed to predict wind speed on the ground from that on the roof, and identified a sheltering effect on the ground by a factor of about four (see Figure 4). Furthermore, the draught speed in the Link Mall was consistently (and significantly) higher than the corresponding external (ground) wind speed. This result also suggests that the problem was suction driven and not wind driven. Low pressure developing within the Atrium was being satisfied by air accessing through the Rousehill Entrance, and (when this route was denied) through the adjacent South Mall Entrance.

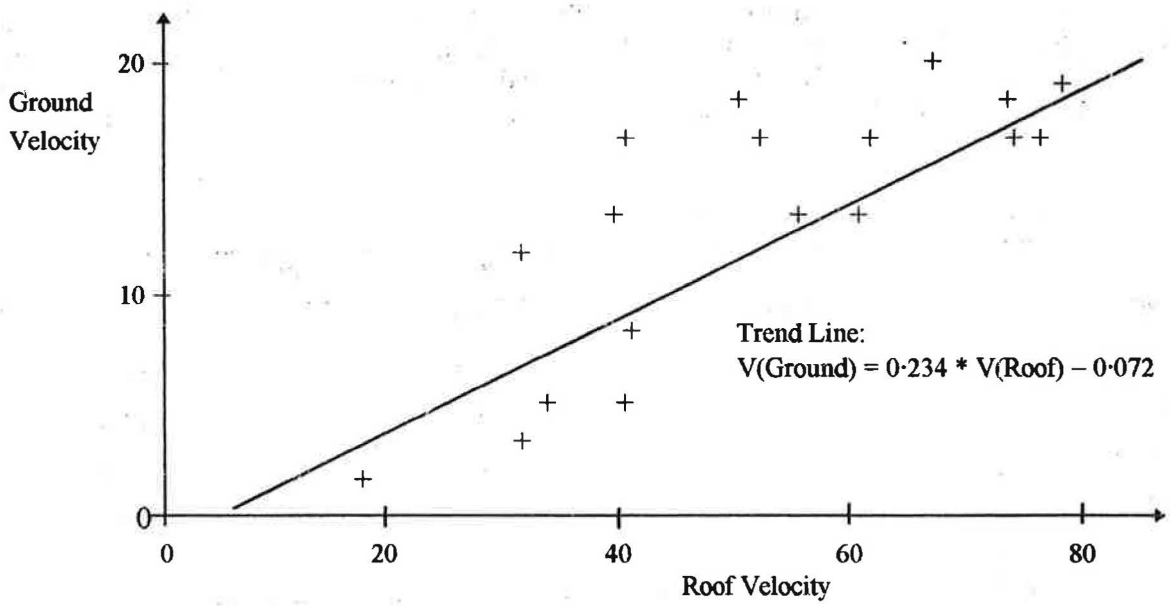

Figure 4 Linear regression model of ground velocity on roof velocity

These various hypotheses were examined further by fitting a multivariate regression model to express the strength of the air flow through the Link Mall (dependent variable) in terms of all six explanatory variables using a forward variable-selection method. Although every single factor was available, the Rousehill Entrance was selected as the primary contributor to the excessive draught flow through the Link Mall, with a subordinate contribution coming from the South Mall alone. No other variable was deemed to have a significant effect. These results are wholly consistent with earlier preliminary findings.

In this context, non-selection of variables carries as much information as the selected variables. The absence of external wind velocities reinforces the view that the problem is not wind driven, and the absence of the state of the vents reinforces the view that the closing (or sealing) of the vents in the roof of the Atrium had little (or no) significant effect on the adverse conditions in the Link Mall.

Attention was then directed specifically to the smoke vents. There was some evidence that the prevailing external wind velocity was significantly lower over the period of monitoring when the vents were taped. Nevertheless the operating characteristics over the various door configurations were remarkably similar. More pertinent was the fact that all air-flow patterns monitored with the Link Mall, when the vents were taped, were uniformly higher than the mean ambient ground wind speed. Once again, this is statistical evidence of a suction-driven mechanism which persists (and could even be aggravated) when the vents are taped. Recorded levels of air flow through the Link Mall under conditions of apparently total enclosure (that is, all doors closed and vents taped) were too extreme to have been the result of simply the internal geometry of the Atrium. The only scenario consistent with the statistical results was excessive leakage from the Atrium roof.

Validation

The blind statistical analysis confirmed the hunch of the design team that the problem was caused by air leakage from the atrium roof. To confirm that the findings were correct a final test was undertaken before the installation of a lobby at the Rousehill was abandoned. On-site smoke tests at the roof of the Atrium proved conclusively that the frames which housed the smoke vents had not been bedded in sealant.

Conclusions

Sealing the gaps around the smoke-vent frames proved a very cheap and effective solution to a hitherto chronic and expensive problem of shopper discomfort. As a result, the developer, retailers and shoppers now have a more agreeable shopping environment.

Furthermore, instead of contemplating the addition of extra doors and lobbies to inhibit draughts (which would have been unnecessary, costly and ineffective) the analysis suggested that certain doors could be removed with no adverse effect. These doors have in fact been removed, and as predicted, no draught problems have been caused.

The use of statistical analysis and CFD proved a powerful combination and successfully resolved a long-term problem within a relatively short period of time. Perhaps the most satisfying aspect of this study is that the design team searched for a permanent solution by identifying and treating the root cause rather than treating the symptoms of the problem.

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