CIBSE NATIONAL CONFERENCE 1999

The use of a Mixed Gas Sensor in the study or Indoor Air Quality and its application to Demand Based Ventilation.

A. Moore, MJ Murray University of Central Lancashire

Demand Based Ventilation systems are potentially valuable in terms of energy saving in building with fluctuating occupation patterns. Most demand based ventilation systems are controlled by CO_2 measurement. However this approach cannot take account of other polluting elements found in indoor air.

This paper will describe the results of a study of the indoor air quality in a recently built university library with continuous ventilation. The literature relating to typical levels of naturally occurring gases, volatile organic compounds and microbes, in indoor air is considered. The range of pollutants in indoor air is discussed and various methods of measuring them are tested and compared.

In particular a mixed gas air quality sensor is used to monitor air quality in an attempt to measure the efficacy of the instrument as controller for a demand based ventilation system.

A questionnaire based on the BRE Office Environment Survey is used to establish the building users perception of indoor air quality.

The questionnaire analysis and the performance of the mixed gas sensor are compared to assess the suitability of the sensor as a controller for a ventilation system.

Results indicate that mixed gas sensor control for demand based ventilation systems may well be the way forward for better air quality and optimum energy conservation.

INTRODUCTION

Good ventilation within buildings is invariably coupled with high levels of occupancy satisfaction (1). Unfortunately, after the oil crisis in the 1970's building services engineers throughout the world have reduced the amount of fresh air introduced into a building because of the high cost involved in heating or cooling fresh air. The idea of controlling the amount of fresh air supplied to a building proportional to the level of occupancy has been desired by engineers for some time, but until recent advancements in fan and sensor technology it could not have been effectively realised.

The high performance of demand based ventilation systems with respect to indoor air quality levels coupled with the potential energy savings are extremely difficult to ignore. The aims of this pilot study were to investigate the relative performance of mixed gas air quality sensors and the feasibility of converting a conventional ventilation system into a demand based ventilation system.

There are a number of ways of controlling the amount of fresh air entering a building. The system could simply involve a counting mechanism assessing the number of people within the building at any time. This type of control has to make the assumption that each person within the building respires at a pre-determined rate only. Physiological experiments have shown that respiratory rate is affected by many different factors such as the ambient temperature, or the amount of clothing worn by the individual. The carbon dioxide sensor was developed as a more specific indicator of respiration levels but their use in the field has been problematic as they are difficult to initially calibrate and quickly become inaccurate.

Contaminants are introduced into the indoor air from internal sources such as human bodies or photocopiers, or from external sources such as vehicle exhaust gases that are then and then distributed through the supply ventilation system or through openable windows. In many cases the location of the intake grille can greatly reduce the amount of externally formed contaminants brought into the building and consequently, the focus changes to the internally produced pollutants that must be diluted and then removed by input and extract ventilation.

Recent research into indoor air quality has tried to quantify the amount of air pollution based on the olf (2) that represents the body odour produced by a person under standard conditions. However occupants are not the only source of contaminants (3) within a building and it is therefore essential that any air quality sensor controlling ventilation levels can recognise a wide range of compounds that appear to be responsible for poor air quality. The mixed gas sensor detects an extensive range of pollutants but has a very simple mode of operation. This study examined the accuracy and relative merits of using an air quality sensor in the field.

Experimental

2.1 The Building

The feasibility of installing a demand based ventilation system is heavily dependent on the occupancy levels and activities occurring within the building. In assessing the performance of the mixed gas sensor it was important to choose a building that had fluctuating occupancy levels and equipment associated with releasing pollutants. After inspecting a number of different building the university's recently built library proved to be the ideal indoor environment to carry out this experiment. The first floor library area was an ideal place to assess the effects of occupancy levels on indoor air quality. In contrast, the library's reprographics area was also investigated to determine the responses of the mixed gas sensors to commercial photocopiers.

The library was constructed with opening windows on most elevations and fresh air is introduced through ductwork and grilles into the deep plan areas of the building. The reprographics area shared the same general ventilation system without any further enhancement.

As the building had only been in operation for a couple of years it was assumed that the ventilation system would not be introducing significant levels of contaminants such as microbes or dust around the building.

2.2 Measurements

The internal levels of nitric oxide and nitrogen dioxide were measured using diffusion sampler tubes. The same method was employed to monitor the levels of ozone and volatile organic compounds but the levels of these pollutants were not significant enough to register a colour change within the sample tube. In the absence of the correct quantitative measuring equipment, a grab sample was taken using a Gresham cylinder and the sample passed through a mass spectrometer to confirm the presence or absence of volatile organic compounds.

The mixed gas sensor was then used to detect oxidisable gases and vapours such as body odours, tobacco smoke, emissions from materials (furniture, carpets, paints and adhesives etc.,) and photocopier solutions (4). The sensor is based on the principle of the Taguchi cell that consists of a sintered semi-conductor tube with an internal heater (Figure 1.) The semi conductor material is highly pourous tin dioxide (SNO_2) formed into a tube to give it a large surface area. The sensor works in a similar way to a catalytic converter with a reversible reaction based on the redox principle. In the ideal case, gases and vapours which come into contact with the sensor's surface are oxidised to carbon dioxide and water vapour. The oxygen required for oxidation is removed from tin dioxide, releasing electrons that in turn alter the resistance of the sensor. The change in resistance can be measured as a change in voltage and this signal can them be used to control the speed of a fan or the position of a damper. In this experiment the sensor had been adapted to illuminate up to 10 LED lamps proportional to the resistance of the sensor.

The sensor was calibrated in the countryside, away from any source of pollution and taken to the library and introduced in to the appropriate area of the library and allowed to warm up for two hours. Samples were then recorded every three minutes and the average reading taken for the time period. During the sampling period a simple head count was taken to assess the occupancy level for the time period.

The sensor was strategically placed away from individuals and equipment to obtain a uniform sample of the air quality. The LED lights were three different colours and were easily visible from a 2 metre exclusion zone.

2. 3 Questionnaire

Measuring the levels of pollutants within indoor air and using the air quality sensor were useful tools in determining the air quality, however, it was also essential to ascertain the regular library user's perception of the indoor air quality and identify any prevalence of sick building syndrome or its associated symptoms. After carrying out an extensive review on questionnaires to establish sick building syndrome, a questionnaire based on the Building Research Establishment's Office Environment Survey was developed (5). The questionnaire was then distributed to all library employees and returned for statistical analysis.

Results

Analysing the data from the air quality sensor and the levels of indoor oxides of nitrogen levels suggested that oxides of nitrogen did not affect the air quality as perceived by the mixed gas sensor. As the levels of nitrogen dioxide and nitric oxide fluctuated during the day the results returned from the mixed gas sensor did not follow the same patterns. (Figure 2.). More significantly, as the numbers of people using the library changed the sensor reacted accordingly with fewer lights lit.

Unfortunately, there were few examples of good air quality within the building during the six days of testing. The most plausible explanations for this is that the sensor was calibrated in the countryside and the datum used was countryside air, therefore, the recordings made in the library were poor in comparison.

Analysis of the data for the first floor library area revealed that on all six test days the level of occupancy was proportional to the recorded air quality, the better air quality being associated with fewer library users (Figure 3.). This suggests that the sensor is sensitive enough to respond to low levels of body odour, equally it reacts accurately throughout a wide range of occupancies.

The sensor responded rapidly to increases in occupancy but as the occupancy levels dropped the sensor displayed poor quality and was slow to react for a prolonged period. This is a known characteristic of the sensor as the contaminants landing on the sensor require oxidising in order to change the resistance of the sensor, consequently, there is a greater lag in sensor response after high contaminant exposure.

During the testing period, care had to be taken with the positioning of the sensor as it became completely sensitised when an occupant used a correction fluid and the period of sensitisation was particularly prolonged by this type of contaminant. Taking a large number of samples over a during the time period helped to obviate the number of these anomalies.

The library enforces a non smoking, drinking or eating policy, however, the air quality was recorded at its lowest levels between 12 :00 p.m. and 3 : 00 p.m. During this time period the population using the library was at its highest , but furthermore, a number of people were observed eating and drinking and the odours released, while not being particularly unpleasant, greatly enhanced the response of the mixed gas sensor. In addition, there was a greater incidence of smoking outside the entrance to the library during the dinner period and the odours that are attached to the smoker are released into the building from clothing and breath.

Having established a relationship between air quality sensor readings and occupancy levels, a similar relationship would have been expected in the reprographics area. The results revealed that this was only the case during extremely low occupancy levels. For the most part, the sensor perceived the air quality in the reprographics area at it's worst recordable level, with all ten indicator lights lit after occupancy levels reached 7 - 10 people. When the photocopiers were in use the air quality recording was never below level 9. In this area, the data showed that occupancy levels were not the only factor in determining air quality.

The environmental survey was deliberately limited to the library staff as most library users were not likely to spend more than eight hours within the building per day. It was felt that regular library users would have been able to answer questions regarding their perception of the air quality but any questions regarding their personal health with respect to the symptoms of sick building could not be attributed to the conditions within the library.

When all the information was collated the results varied from the Office Environment Survey recording higher levels of certain symptoms and lower levels of others. The occurrence of lethargy was the highest reported symptom at 70% and this was much higher than the office environment survey figure of 57% (Figure 4.). Given the limited sample size, the figures compared quite favourably with headaches reported at 45% compared to the 43% reported in the office survey. The figures for dry eyes and dry nose were much lower in the library when compared to case studies.

The BSI_5 level of the building was calculated at 1.8 (Figure 5.). At this level there is, strictly speaking, a case for taking action. Further analysis was made assessing the Personal Symptom Index and no member of staff had a $PSI_5 = 5$ and the majority of results reported two or less symptoms.

Discussion

The causes of sick building syndrome are still questionable but case studies have shown that in well ventilated buildings the occupants show a lower level of dissatisfaction with the environment and are less prone to associated illness. The effectiveness of demand based ventilation systems is therefore dependent on the sensor responding to the air quality in the same way as the building occupant.

In the field the mixed gas sensor was extremely sensitive to both occupancy levels and the introduction of odours such as the peeling of an orange or the use of correction fluid. One of the major advantages of the sensor is it's ability to respond to an incredibly wide range of odours. However, the sensor cannot determine between acceptable odours such as perfume from unacceptable odours like tobacco smells. This would appear to be a disadvantage , however, the appreciation of good or bad smells varies from person to person and consequently, the ventilation system should be able to remove or dilute all odours.

The relatively simple operation of the sensor makes it a very durable piece of equipment and it be can be easily moved outside, without damage, to be calibrated. Throughout the day the recordings made by the sensor were scrutinised to check that the sensor had not drifted during the day and it would be interesting to establish the sensitivity over a longer period. In theory the sensor should burn off all odours that pass through the tin dioxide, however laboratory experiments have shown that excessive dust or airborne grease can block the tin dioxide pores and reduce the sensitivity.

The changes in the sensor's resistance can be easily transformed into control signals to control ventilation plant. One common application to constant volume systems would be to open the fresh air damper and close the re-circulation damper if the air quality deteriorated. Further energy savings can be made by implementing a variable volume ventilation system The sensor signals are used to determine the flow rate required, which is then ultimately achieved by altering the pitch angle of the fan's impeller.

The reprographics area was predominately identified as an area of poor air quality by the sensor and a separate demand based ventilation system would be advisable in this area. The same philosophy could be applied to other areas and rooms that might require enhanced ventilation, for example, smoking rooms that are only occupied during break times.

The staff survey established that the building environment was good even though there was a high level of reported illness. The survey was carried out during the winter months and consequently, the effects of cold and flu could have been inadvertently construed as symptoms of sick building syndrome. If the survey had been carried out every two months for a full year it might have allowed correction factors to be applied for seasonal illnesses. In addition, no correction factors for gender or position within the company were applied that would have affected the final result.

Conclusions

Buildings such as the university library are perfect candidates for demand based ventilation system as the amount of fresh air supplied to the building can be modulated to suite the occupancy level. The advantages of this type of system are two fold. Firstly, the level of air quality can be maintained at a pre-determined set point throughout the building. Secondly, by modulating the amount of fresh air delivered in to the building the efficiency of the components of the system such as the fan and the heating and cooling coils are dramatically improved. However, the air quality and potential savings are dependent on the accuracy of the mixed gas sensor and associated controls. This initial study has shown that the air quality sensor operates effectively within the an area of varying occupancy. Furthermore, the study has shown that the reprographics area requires a greater level of ventilation to cope with the pollutants produced by the associated machinery and the mixed gas sensor would be the most suitable assessor of the ventilation level required.

References

1 Borbeau J. Brisson, C. Allaire, S. Prevalence of the sick building syndrome symptoms in office workers before and after being exposed to a building with an improved ventilation system. Occupational and Environmental Medicine. 1996; 53: 204 - 210.

2 Fanger PO, Introduction of the olf and the decipol units to quantify air pollution perceived by humans indoors and outdoors. Energy Buildings. 1998; 12: 16.

3 Crump D R, Volatile Organic Compounds in Indoor Air. Environmental Science and Technology. 1995; 5: 10 - 21.

4 Meier, S. Demand Controlled Ventilation in restaurants: mixed gas or carbon dioxide sensors as a reference variable? Proceedings of the 6th International Conference on Indoor Air Quality and Climate. (Indoor Air '93); 2: 111 - 116.

5 Raw GJ, A Questionnaire for studies of sick building syndrome. BRE Report, London Building Use Studies, 1987.

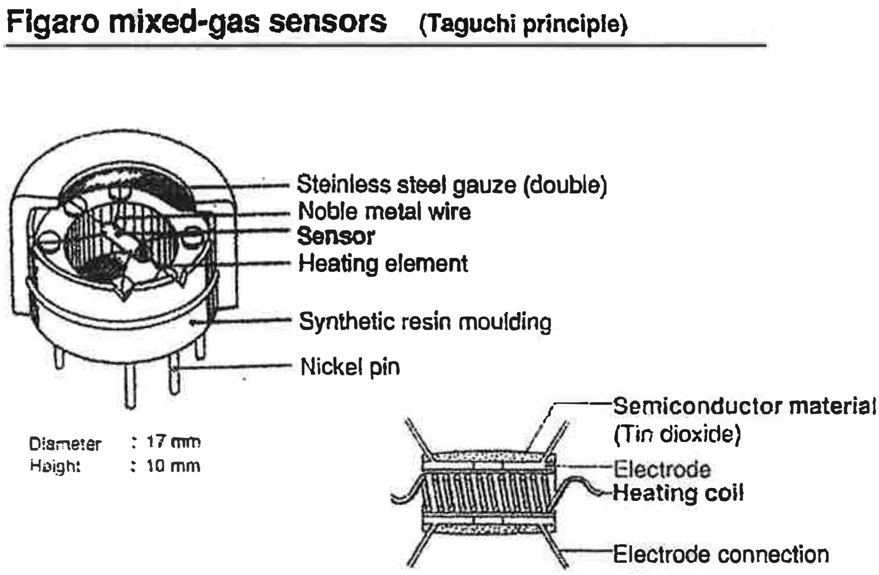

Figure 1 . The Mixed Gas Sensor.

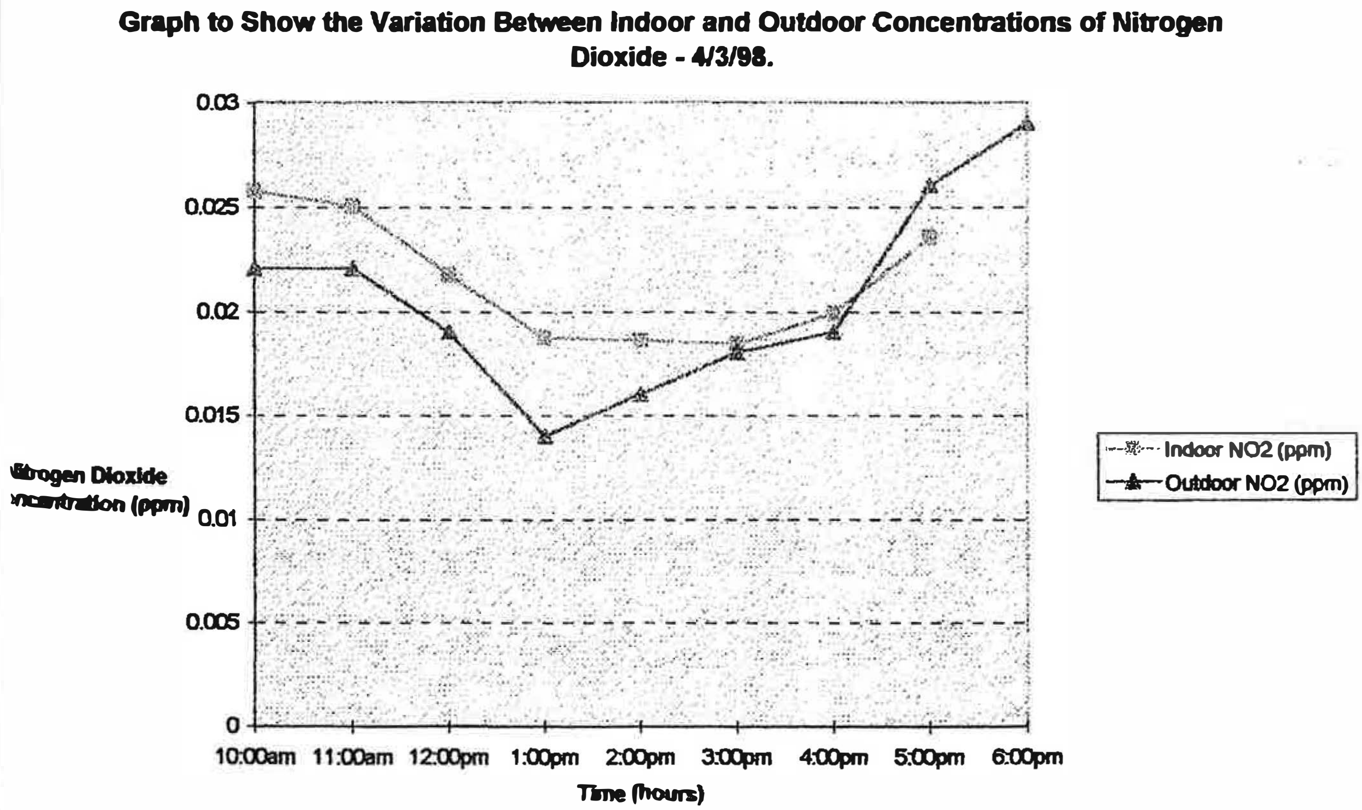

Figure 2.

Table of Air Quality Testing Results 4/3/98.

Time	10:00am	11:00am	12:00pm	1:00pm	2:00pm	3:00pm	4:00pm	5:00pm	6:00pm
Temp. (oC)	21.5	22	22	21.8	22.5	22.8	22.8	22.8	22.8
R. H.(%)	66.3	69	67	68	68.7	68.7	67.3	69	68.5
AP (mmHG)	747.2	747.6	747.2	747.1	747.2	747.1	747.3	747.1	747.3
Noise (dB[a])	74.1	74.6	75.7	78	75.9	80.9	74.1	82.1	75.3
First Floor Library Area									
Head Count	36	52	58	73	66	75	60	47	37
Air Quality Level									
1 = Good 10 = Poor	2	4	4	6	6	7	7	4	2
Ground Floor Photocopy Area									
Head Count	6	7	10	14	4	6	8	8	3
Air Quality Level									
1 = Good 10 = Poor	9	10	10	10	10	9	10	10	9

Table 1.

Graph to Show the Effect of Occupancy Levels On Air Quality Measurements from a Staefa Mixed Gas Sensor - 4/3/98.

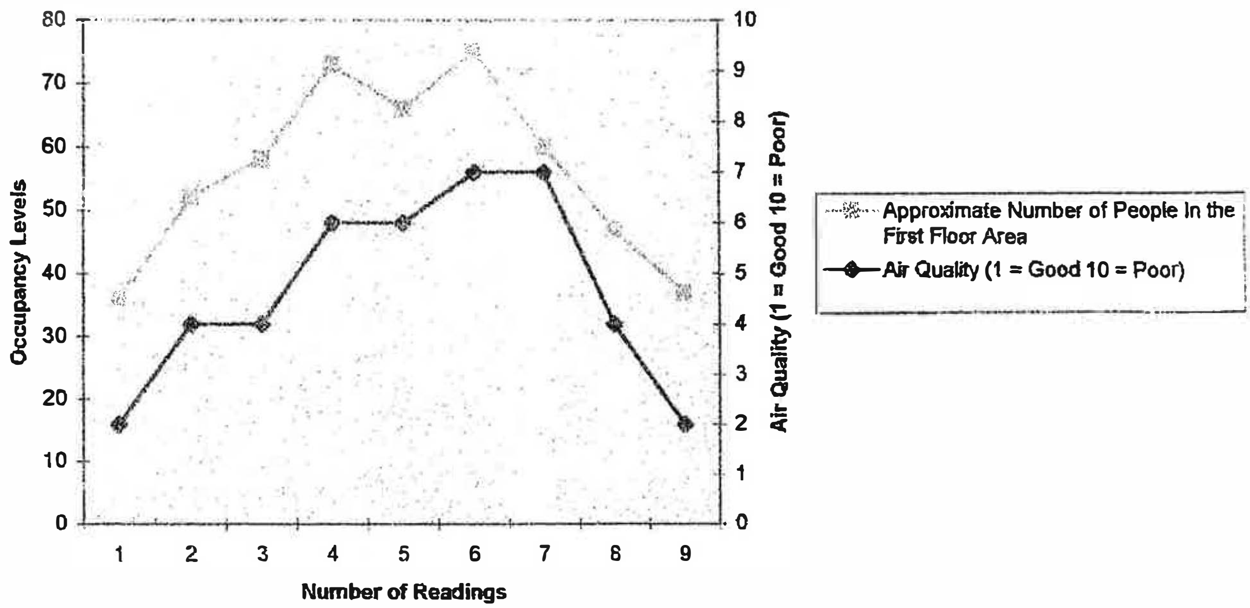

Figure 3.

Graph to Show the Percentage of Reported Symptoms By Staff at the University of Central Lancashire Library.

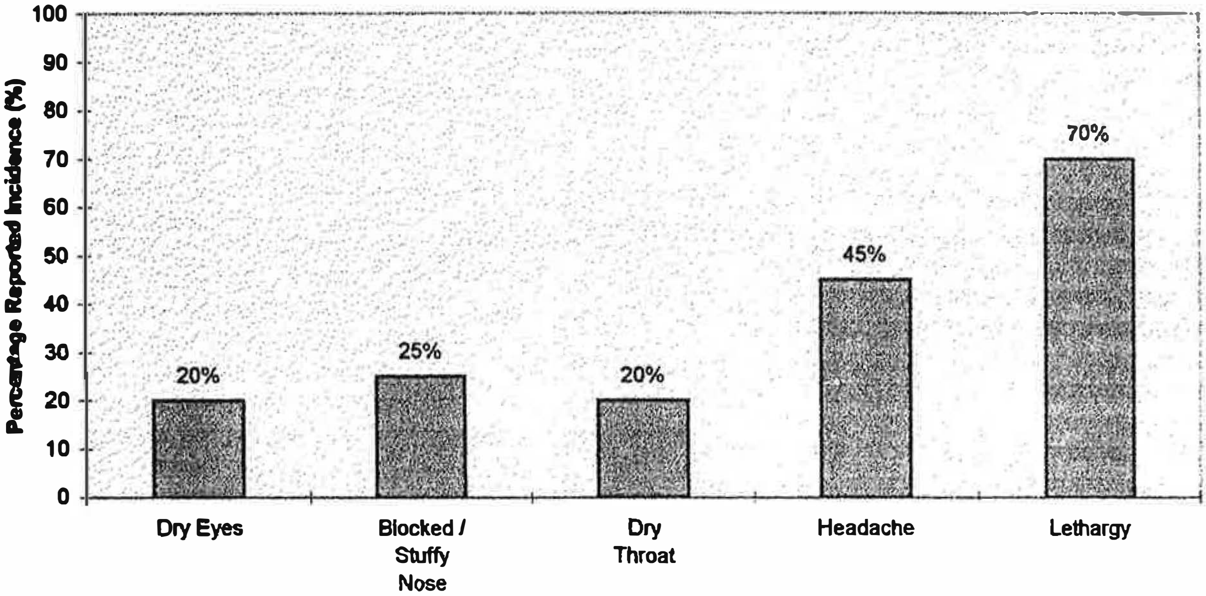

Figure 4.

Pie Chart Showing the Percentages of Person Symtom Index for Library Staff at the University of Central Lancashire.

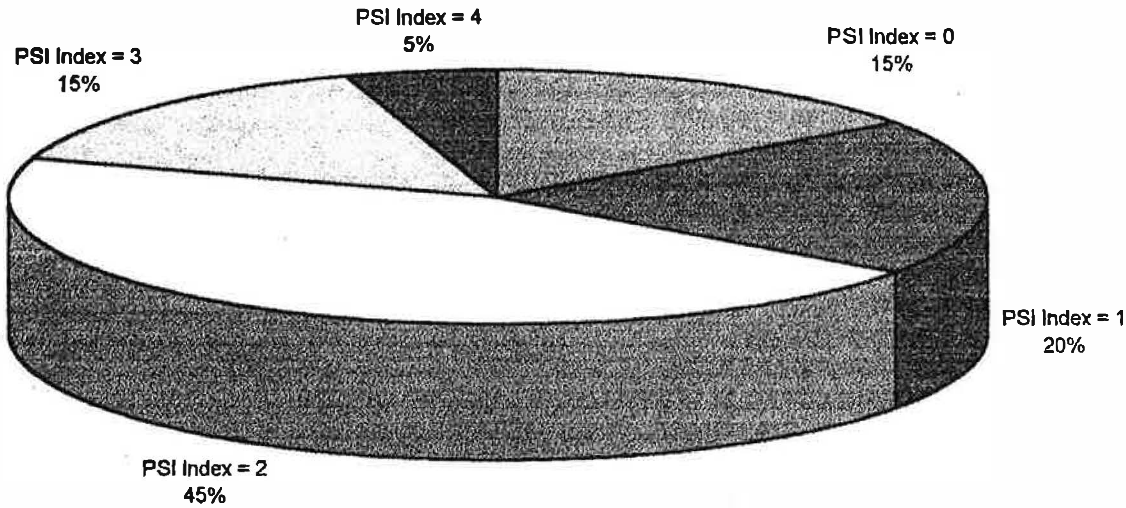

Figure 5.