CONCLUSIONS

Buildings designed for 2.5 l/s/occ (5 cfm/occ) of outdoor air per occupant may experience capacity problems if outdoor air settings are increased to 10 l/s/occ (20 cfm/occ) per occupant. Buildings designed for 2.5 l/s/occ (5 cfm/occ), but with slight excess capacity (about 10 to 20 percent excess cooling capacity for temperate climates), appear to be capable of meeting the 10 l/s/occ (20 cfm/occ) requirement of ASHRAE 62-1989. When the extra capacity is not available, problems in maintaining thermal comfort may be significant unless the capacity issue is properly addressed. Caution needs to be exercised when advising building owners to increase outdoor air flow rates in existing buildings.

The energy cost impacts of increased outdoor air flows are dependent on the relative changes in heating and cooling energy occurring in each of the three seasonal temperature bins introduced in this paper. The increased cooling energy demand in summer and heating energy demand in winter is counterbalanced by decreases in cooling energy demand in winter and the transitional seasons. The effect on annual energy cost depends on the relative magnitude of these changes, the relative importance of the temperature bin for that climate zone, and the relative prices of gas and electricity. The net effect typically results in a marginal increase or a slight decrease in energy costs. Warmer climates will experience a greater energy cost increase due to the larger increase in both sensible and latent cooling loads. Colder climates will have mixed results, but buildngs with high internal gains will likely experience a higher energy cost increase in colder climates.

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A GAS SENSOR ARRAY FOR MEASUREMENT OF INDOOR AIR POLLUTION - PRELIMINARY RESULTS

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ABSTRACT

An array of gas sensors was used to evaluate air contaminants in 36 spaces, concurrent with judgements by a trained sensory evaluation panel. Data were processed by advanced pattern recognition techniques to discern patterns relating sensor readings to voted indoor air pollution (IAP) level in decipol. The mean vote of the panel could be predicted with a mean error of 2.9 decipol and a standard deviation of error of 2.4 decipol, comparing favorably with panel member votes across all spaces with 2.1, and 2.9 decipol respectively. While the results of this study are promising, the small number and variety of sample spaces limit the generality of the recognized patterns. Additional work to extend the capabilities of this method is ongoing.

INTRODUCTION

A technique for direct measurement of indoor air pollution (IAP) level is desirable for building diagnostics and for continuous monitoring of indoor environments. An IAP sensor would allow control actions such as modulation of outdoor air and zone dampers for ventilation, operation of air cleaning devices, or alarming of unhealthy conditions. Various analytical techniques exist for measurement of low concentrations of gases and vapors in air, and even a few reasonably priced sensors can monitor fairly low concentrations of some compounds. These measurements are not representative indicators of IAP, because they do not reflect human response.

One of the most promising proposed indicators of IAP is the sensory evaluation-based decipol scale, because it focuses on human response (Fanger, 1988). The decipol is primarily a measure of unpleasant odor concentration, but may also be affected by other sensory inputs. While the human olfactory organ is a very sensitive detector of many chemicals that are of concern in indoor air, the receptors quickly become saturated, and the perceived response diminishes. To avoid this adaptation to odorous environments, panelists must enter the environment to be judged from a clean environment, usually outdoors, and quickly make a judgement on their initial perception. To maintain consistency in judging the decipol level, panelists must undergo a daily calibration.

Practical problems in using the decipol to judge the pollution level in indoor environments includes the inability to perform continuous measurements, daily calibration requirements, the lack of portability of a panel of 10 people or more, and the overall expense of the technique. As a measure of IAP, the decipol is essentially limited to those contaminants that have an odor. Odor can not be a complete indicator of IAP however, even when consideration is limited to gaseous contaminants. Carbon monoxide is a common and potentially harmful air contaminant that does not have a detectable odor. In general, irritation experienced by occupants after extended exposure will not necessarily correlate with odor response.

An ideal sensing system for measuring IAP would have the following features:

1. human-equivalent response for odors, unhealthful non-odorous compounds, and irritants
2. capability to perform real-time measurements without sensors becoming saturated
3. stable and accurate operation without frequent calibration
4. portability for diagnostic activities
5. small size and low cost for permanent installation

As a first step toward achieving such a sensing system, this project utilized advanced pattern recognition (PR) algorithms to process signals from an array of sensors and instruments that detect various gas concentrations. The outputs of the PR algorithms attempt to mimic the judgements of a human sensory panel.

METHODS

Panel Training

A panel of volunteers were trained to judge known decipol levels created by specific concentrations of acetone (Bluyssen et. al., 1989). These concentrations were generated in jars that were fitted with fans and diffusion cones. Although a climate chamber was not available, a room was used for testing and training the panel that had fairly accurate temperature control at approximately 22 C. The outdoor air damper was open at least 80 percent, and background acetone concentrations stabilized at approximately 1.5 decipol. Selection of members for the panel was determined by a detection test and a sensitivity test. The 11 top performers of 25 subjects were selected for the final panel.

Four milestone reference concentrations of 1, 5, 10 and 20 decipol above background were set up as the basis for training and later calibration. Panel members were not allowed to wear perfume, smoke, eat or drink for one hour prior to training or testing sessions. Several days of training were completed with panelists judging unknown decipol levels followed by feedback on improving the accuracy of votes, and reminders to judge the unpleasantness rather than the intensity of the odors. The mean error for the panel during training was 1.9 decipol, and the standard deviation of error was 1.7 decipol. Small variations between panel members are of minor consequence, because all votes are averaged during evaluations. Figure 1 shows average panel performance during training, demonstrating that the panel was well balanced.

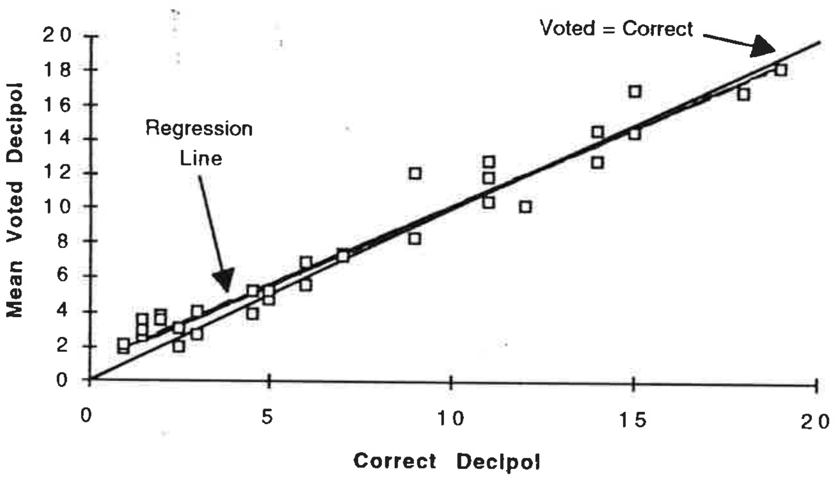

Figure 1. Mean panel decipol vote vs. correct decipol for each training sample

In addition to the acetone training, several jars containing a variety of building materials were judged to allow the panel members to become accustomed to more realistic, complex odors, and to help relate those odors with the unpleasantness of the acetone milestones.

Sensor Array

For this preliminary study, the sensor array was assembled on the basis of previous work in the field of odor sensing (Shurmer, 1990) and on commercial availability. The array consisted of: temperature, eight tin-oxide gas sensors, and 11 optical filters in a photoacoustic infrared gas detection instrument. The specific tin-oxide sensors were listed by the manufacturer for detection of ethanol, hydrogen sulfide, ammonia, cooking gases, organic vapors, combustible gases, air quality, and carbon monoxide. The sensors were mounted in a chamber that had air forced through it by a small fan. Gas data were sampled by a datalogger and later downloaded to a computer.

The 11 optical filters for the photoacoustic instrument were calibrated for water vapor, carbon dioxide, acetone, ethanol, toluene, propane, ammonia, vinyl chloride, chloroform, benzene, and formaldehyde respectively. Since the instrument could only monitor five gases plus water vapor at one time, air samples were collected in teflon sample bags and analyzed after the space evaluations were completed. Concentration readings were stored in the on-board memory of the instrument and later downloaded to a computer.

Neither the tin-oxide sensors or the photoacoustic instrument have a high degree of compound selectivity, but rather respond to certain overlapping groups of compounds. In attempting to mimic the response of the human olfactory organ, this characteristic is probably quite desirable. In humans, a limited number of receptors are used to recognize hundreds of odors over wide concentration ranges. This feat is accomplished through cross sensitivity between receptors, and complex pattern recognition capabilities of the brain. A characteristic of IAP is that a single compound from a multiple compound contaminant source can often serve as a marker for all of the compounds. Even if all compounds can not be detected by the sensors in the array, a sufficient number of marker compounds may be detectable to adequately classify the decipol level of a given sample.

Building Space Evaluation

Evaluations took place over several days. After a daily calibration on the acetone milestones, the human sensory panel was taken to a variety of interior building spaces to evaluate IAP level in decipol. Prior to evaluating each space, the panel was taken outside for several minutes of refreshing, and to perform a low decipol evaluation. To limit the effect of olfactory saturation, panel members voted immediately on entering the space to be evaluated. The sensor array was used to take nearly concurrent readings in the same spaces, and bag samples were collected for later analysis.

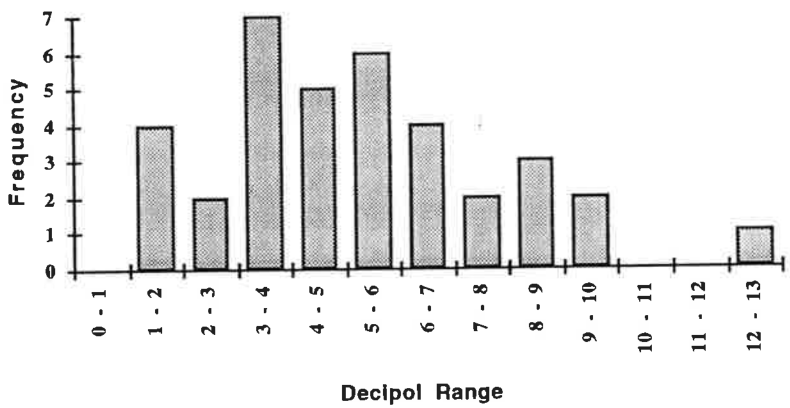

Figure 2. Distribution of voted decipol in 36 evaluated spaces.

A total of 36 evaluations of 33 different spaces were performed in this manner. The selected spaces encompassed a variety of functions, interior types and locations within a large facility with approximately 1000 occupants. The facility consists of six interconnected buildings constructed between 1900 and the 1970s. Spaces included offices, hallways, storage areas, equipment areas, stairwells, an auditorium, and a computer room. Mean voted decipol for the panel ranged from outdoor values as low as 1.2 to indoor values from 3.3 to 12.7. A histogram of the data set sorted into decipol bins is shown if Figure 2.

Pattern Recognition Analysis

Four pattern recognition techniques were used in this study to predict the human sensory response to IAP. These techniques were:

1. artificial neural networks
2. direction cosine method
3. Euclidian distance measure
4. Tanimoto similarity measure

Each of these techniques use different aspects of the data to perform classifications. Artificial neural networks (ANNs) create a hyperspace model of the known data set. Unknown samples are then mapped into the model to predict decipol. An example of the multi-layer feedforward architecture used is shown in Figure 3. The ANN is iteratively "trained" to adjust the weights of the network until the output is within an error tolerance of the training output. The other PR methods are not "trained", but rather use the known data set as a basis of comparison for unknown samples. The direction cosine method uses the relative magnitudes between known samples and unknown samples for classification. The Euclidean distance measure calculates the distance between the known and unknown samples in multi-dimensional space. The Tanimoto similarity measure classifies samples based on similarities between the elements of known and unknown samples. Detailed descriptions of these techniques can be found in Lippman (1987) for ANNs, and Kohonen (1988) for the other techniques.

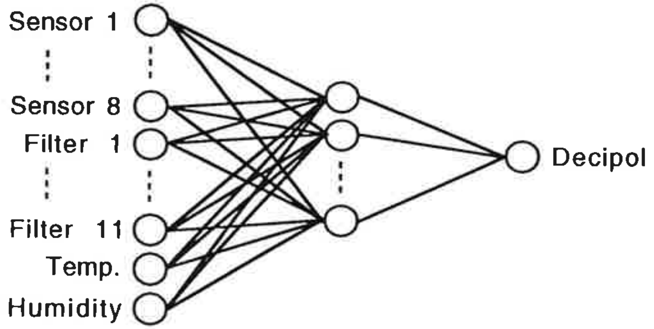

Figure 3. Artificial Neural Network Architecture

Raw sensor data were pre-processed by averaging real-time readings over each sampling period. Prior to applying the PR techniques, a correlation analysis of the data set was performed, in which no single sensor was found to be highly correlated with decipol. All of the tin-oxide sensors except the carbon monoxide and the indoor air quality were highly correlated. These sensors were also highly correlated with the dew point measurement of the photoacoustic instrument, even though the dew point only varied from -1 C to 8 C. The humidity dependence of tin-oxide sensors is well known, but little additional contaminant response was observed.

Several of the highly correlated sensors were removed from the final array, because they provide little new information for recognition of patterns. The carbon monoxide sensor was also dropped because it did not appear to detect changes between spaces. Only the tin-oxide sensors for organic vapors, ammonia, air quality, and cooking gases were used in the final sensor array, although PR performance was initially analyzed with all the tin-oxide sensors. The real-time dew point from the photoacoustic instrument was used for humidity.

The data on panel judgements and the corresponding sensor data were divided into a known set and an unknown set. The known set was used to train the ANN, or as reference values for the other PR methods. The PR algorithms were then used to process the sensor readings from the

unknown set, generating predicted human responses in decipol. To evaluate the performance of the algorithm, these decipol predictions were compared to the voted decipol of the unknown set. This procedure was performed for three different combinations of known and unknown data, to ensure that the sets were not biased.

RESULTS

Comparison of Pattern Recognition Techniques

The performance of PR techniques was compared by calculating the mean error and standard deviation of error of each method. The mean voted decipol was taken as the correct value for the space. The best technique would have the lowest mean error and the lowest standard deviation. The best performance was obtained on different known and unknown data sets, with a mean error of 1.6 decipol for the Euclidian method, and a standard deviation of error of 2.0 decipol for the ANN. The error results for the best configuration of each PR method are tabulated in Table 1 in decipol, as the means across the three known and unknown data sets.

Table 1. Mean error and standard deviation of error for four pattern recognition techniques, averaged across three known and unknown data sets.

technique	mean error	S.D. of error
ANN	2.9	2.4
cosine	2.6	2.6
Euclidian	2.2	2.9
Tanimoto	2.2	3.0

The Euclidian and Tanimoto techniques had the lowest mean error, the ANN had the lowest standard deviation of error, and the cosine technique had intermediate results. No technique was clearly the best. Performance of the redundant sensor array was inferior in each case.

Comparison of Pattern Recognition Techniques to Sensory Panel

Mean error and standard deviation of error were also used to judge the performance of the PR techniques relative to the mean voted decipol of the panel which was taken as the correct value. The mean error and standard deviation of error of panel member votes across all spaces was 2.1 and 2.9 decipol respectively. The best mean error performance of a PR technique was the Euclidian method with a minimum of 1.6 on a single data set, and an average of 2.2. The best PR technique for standard deviation of error was the ANN, with a minimum of 2.0 decipol and an average of 2.4 decipol. In essence, the Euclidian method and the ANN were more consistent in predicting space decipol levels than the members of the panel. A plot of decipol predicted by the ANN against correct decipol, the mean of panel votes, is shown in Figure 4.

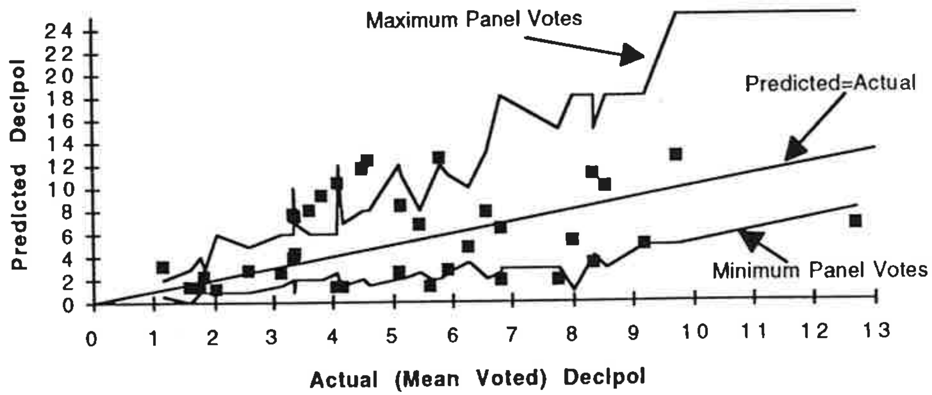

Figure 4. Predicted decipol by the ANN vs. Actual Decipol, bounded by panel vote range.

DISCUSSION

A sensor array coupled with a PR technique was successfully used to mimic the decipol judgements of a human sensory panel. Through correlation analysis, redundant sensors were identified and removed from the final array, resulting in improved PR performance.

The results of this study are very encouraging, but because of the small number of evaluations performed on a limited variety of spaces, the patterns extracted from the data are likely not applicable to all occupancy conditions, construction types, system performance levels and climatic conditions. If developed from a broader data base, a similar sensor array and PR technique may be able to reliably predict IAP decipol levels over a broad range of spaces. If additional information can be incorporated into the PR algorithm on irritation potential of odorous and non-odorous compounds, the array can be even more useful as a tool for indoor environmental diagnostics and on-line monitoring.

To make the results more meaningful and more consistent, the following improvements are planned for future work on this concept:

1. increase the number of panel candidates
2. improve the training environment by using a climate chamber
3. improve the training by using a mixture of compounds rather than acetone alone
4. evaluate a much larger sample of spaces in different buildings, and in various climates
5. increase the uncorrelated sensors in the array, and add sensors for other environmental parameters, such as noise and lighting, that might impact a panel's judgement
6. input criteria to the PR technique to address compounds that can have an irritation effect on increasing exposure

A more detailed study is in progress which incorporates most of these improvements.

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INCREASED VENTILATION REDUCES GENERAL SYMPTOMS BUT NOT SENSORY REACTIONS

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ABSTRACT

This paper deals with the relationship between sick building problems and the fresh air volume flowrate. Seven junior High School buildings were investigated and two school-classes at each school, in total 264 pupils, were asked to fill in a comprehensive questionnaire regarding their own health and the indoor environment at the school. At the same time indoor climate and technical measurements were conducted. The investigation reveals the magnitude of hypersensitivity among Norwegian school children. It also demonstrates the magnitude of indoor climate problems. The measurements and the self-reported questionnaires indicate that effective ventilation is only a part of the solution to indoor air problems.

INTRODUCTION

The requirements that produce acceptable indoor climate are considerably difficult to quantify. It is especially difficult to achieve a consensus as to the amount of fresh air that is necessary. Since the energy consumed by ventilation systems rises with increasing proportions of outside air, it is important from an energy-economic viewpoint that this proportion does not exceed what is considered acceptable with regard to human health, well being and productivity. In school buildings it is especially important that the indoor environment is satisfactory on account of learning ability, progress and academic achievements.

This paper deals with the relationship between sick building problems, ventilating systems and the outside (fresh) air volume flow rate. At the same time the magnitude of allergic or hypersensitive pupils is fixed and investigated in order to determine whether they had more sick building problems than the "healthy" portion of the children. The paper is based on 3 investigations conducted in Trondheim, Norway during the years 1989-91.

METHODS

Seven junior high-school buildings in Trondheim (Nordic climate) were investigated during the autumn of 1989, (1), (2). At one of the schools the investigation was repeated in the autumn of 1991, (3). All the schools, with the exception of one, were built in the years 1970 to 82. The last school, G, was built in 1887 but was completely renovated in 1983-86. Some main data concerning the buildings is shown in table 1.