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ASSESSMENT OF THE PERFORMANCE OF DOMESTIC-KITCHEN EXHAUST SYSTEMS

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1. INTRODUCTION

The trend towards well-insulated housing has led to increased concerns about indoor air quality and high humidity levels. Kitchen exhaust systems, including extract fans and wall-mounted hoods, are widely used as a means of removing moisture, grease, fumes and smoke from domestic cooking areas. The British Code of Practice, BS5250(1), recommends a mechanical extract rate of $288m^3/h$ and is intended as a standard for design calculations made by fan manufacturers.

Little experimental work has been carried out to determine the actual extract rate of typical exhaust systems installed in domestic kitchens or to assess the effectiveness of these systems in preventing the migration of moisture and cooking contaminants to the rest of the house(2-5). The present investigation involved the use of a microprocessor-controlled tracer gas system to measure ventilation rate and interzone air movement in a house equipped with a wall-mounted hood and a kitchen extract fan. The airflow velocities under the wall-mounted hood were also measured using an omnidirectional hot wire probe. The results of this study provide quantitative data on the effectiveness of a typical kitchen extract fan and wall-mounted hood installed in a house.

THEORY AND ANALYSIS

The concentration decay technique was used to determine ventilation and interzone airflow in the house. This method involves an initial injection of a known amount of tracer gas into a zone (e.g., kitchen) followed by a period of mixing to establish a uniform tracer gas concentration. The decay of tracer gas is then measured. Assuming that the concentration of tracer gas in the outdoor air is negligible, and that there is no source of tracer gas within the zone, the ventilation rate can be given by the following equation:

$$I = (1/t) \ln (C_o/C_t)$$

To measure airflow between two zones (e.g., living room and kitchen), tracer gas is injected in zone 1 which has all doors and windows closed. Following tracer gas mixing, the communication door between the two zones is opened and the concentration evolution is measured in the two zones. Once the change in tracer gas concentration is established, airflow rates can be estimated using the continuity and conservation equations.

The building is assumed to consist of a number of zones 0, 1, 2, .., N, which are connected by airflow passages. Applying tracer gas volumetric balance equations to zone j, we obtain:

$$V_j \, dC_j/dt = \sum_{i=0}^{N} F_{ij} C_i - \sum_{i=0}^{N} F_{ji} C_j \quad (\text{for } i \leq j \leq N) \qquad (1)$$

The total flow into zone j must equal the total flow out of the zone and is given by the conservation equation:

$$\sum_{i=0}^{N} F_{ij} = \sum_{i=0}^{N} F_{ji} \quad (\text{for } i \leq j \leq N) \; (F_{jj} = 0) \qquad (2)$$

Where V_j is the volume of the jth zone, C_j is the tracer gas concentration in the same zone, dC_j/dt is the time derivative, F_{ij} is the airflow rate from the ith to the jth zone, F_{ji} is the flow rate from the jth to the ith zone. Zone 0 in the model represents the external air and is assumed to have an infinite volume. The concentration of tracer gas in this zone is assumed to be zero. The above equations for the two zone situation (N = 2) can be solved using one of the analysis methods described by Riffat(6). A method based on the Sinden(7) model was used to analyse the present data as this minimises the errors introduced by the uncertainties in tracer gas measurements.

2. INSTRUMENTATION AND PROCEDURE

Measurements were carried out in a house to study the effect on ventilation and interzone airflow of a kitchen extract fan and a wall-mounted hood unit. A microprocessor-controlled tracer gas system, Figure 1, capable of taking samples as frequently as every 5 seconds, was used to determine airflow rates. In essence, the tracer system incorporates solenoid valves, tracer gas sampling bags, a pulse pump, a microprocessor-based controller, a manifold and a by-pass valve. The short sampling period is achieved using a specially designed microprocessor controller. This contains a central processing unit and a programme memory with a capability of 60 input/output. The tracer gas system is flexible and can be used for on-site analysis or for grab-sampling. On site analysis was used for this investigation and involved connection of the sampling system to a portable gas chromatograph so that tracer gas samples could be analysed immediately.

The portable chromatograph consists of a 6-port valve connected to a 0.5 ml loop, a column, a chromatographic oven and an electron capture detector. The system incorporates a microcomputer, a parallel printer and interface cards for both analogue and digital data.

Airflow rates were determined from measurements carried out using the single-tracer gas method. One of several tracer gases could be used but sulphur hexafluoride (SF_6) was chosen for this work as it has desirable characteristics in terms of detectability, safety and cost. In addition its suitability has been demonstrated previously by its successful use in other air movement studies[8,9].

Air velocities beneath the wall-mounted hood unit were measured using an omnidirectional hot-wire anemometer. The anemometer was made by Airflow Development Ltd and had an accuracy of ± 2%. The anemometer was mounted on a traversing device which allowed measurements of air velocities in horizontal and vertical directions (i.e., X-Y directions).

Temperature measurements were carried out at various points in the kitchen and living room using copper-constantan thermocouples. The outside temperature and windspeed during the measurement period were also recorded.

3. RESULTS AND DISCUSSION

3.1 Ventilation rate in the kitchen

Measurements were carried out in the kitchen of a four-bedroomed detached house fully fitted with double-glazed windows and doors, see Figure 2. The kitchen had a volume of $42m^3$ and was equipped with an extract fan and a wall-mounted hood unit. The extract fan operated at a single fixed speed but the fan of the hood unit provided a choice of three speeds settings.

extraction unit is likely to provide more effective capture of moisture, grease and other vapours than a simple wall-mounted extract fan.

3.2 Airflow velocity profile of the wall-mounted hood

Air velocity measurements were carried out in the horizontal and vertical directions beneath the wall-mounted hood under conditions of zero thermal buoyancy. Figure 6 displays the measured velocities in the X-X and Y-Y planes for the wall-mounted hood running at speed 3. It is clear from this figure that the air velocity is large in the central area just below the filter section but decreases rapidly with increasing distance from the filter section. Even at a distance of 200mm above the cooking surface the air velocity was negligible within the measurement accuracy of the experiment. This means that in this region the performance of the hood is mainly dependent on the upward thermal buoyancy force created by the elevated temperature of the cooking surface. The low drag velocity of the hood in the area close to cooker surface could well result in significant quantities of moisture, grease and other contaminants escaping to adjacent rooms. Future work will include the use of a flow visualisation technique to study the flow of contaminants between the cooking surface and the filter section of the wall-mounted hood unit.

3.3 Interzone airflow between the kitchen and living space

Experiments were carried out to determine the effect of the wall-mounted hood and kitchen extract fan on interzone air flow through a doorway (0.75m x 1.98m) between the kitchen and the living space. Figure 7 shows the variation of tracer gas concentration with time when both the wall-mounted hood and the kitchen extract fan were switched off. The temperature of the kitchen and living space was 20°C, and the outside temperature was 18°C. Figure 8 is a schematic diagram of the interzonal air flow when neither extraction system is running. Under these conditions the airflow rate from the living space to the kitchen (F_{12}) was equal to the airflow rate from the kitchen to the living space (F_{21}) and the air exchange rate between the living space and outside was negligible.

Experiments were then carried out with the fan of the wall-mounted hood running at speeds 1, 2 and 3. Figures 9 and 10 show the variation of tracer gas concentration with time for speeds 1 and 3 and Figures 11 and 12 are schematic diagrams of the interzonal air flow for these experiments. Figures 11 and 12 show that when the extract hood was in operation, the airflow rate F_{12} was greater than F_{21} and the air exchange rate between the kitchen and the outside environment was larger than when the extract hood was switched off.

Tests were carried out to compare the effects of the wall-mounted hood and the kitchen extract fan on interzonal airflow. Figure 13 shows the concentration versus time relationship for air flow between the kitchen and the living room when the extract fan is running. The schematic diagram for interzonal airflow is presented in Figure 14. This figure shows that the kitchen extract fan has a much greater effect on interzonal airflow than the wall-mounted hood.

Finally we carried out measurements of airflow through the doorway between the kitchen and the living space under conditions of different temperature difference. The total airflow rate (in m^3/h) was found to vary in accordance with:

$$F = 2487.6\,(\Delta T/T)^{0.18}$$

where ΔT = Average temperature difference between the two zones (K)

T = Mean absolute temperature of the two zones (K).

For example, a temperature difference of 5°C would result in an airflow rate of 1194 m^3/h through the doorway. This indicates that the flow of contaminants from the kitchen to adjacent rooms would only be prevented by the use of a fan with a capacity four times that recommended by the British Standards Code of Practice. As this would be impractical in most domestic situations, the importance of closing the kitchen door during cooking periods is clear.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations can be drawn from this investigation:

1. The fan extract rates measured in this investigation were found to be significantly lower than that recommended by the BS5250 and are unlikely to be sufficient to provide effective removal of cooking contaminants.

2. Airflow from the kitchen to the living room through an open doorway was found to be large even at negligible interzonal temperature difference. This implies that the existing kitchen and wall-mounted hood units are unable to prevent the movement of moisture and cooking contaminants from the kitchen to the rest of the house.

3. Airflow velocity measurements indicated that the wall-mounted hood unit has a low capture efficiency at the cooking surface.

4. Further work is required to examine the performance of a range of fan and hood designs in order to provide quantitative data and guidelines on the optimum deployment of extract fans and hoods.

5. Manually controlled fans are often under-used as a result of the undesirable levels of vibration and noise they produce. Methods are needed to reduce these factors, if extract fans are to gain wider acceptance as a means of removing air-borne contaminants.

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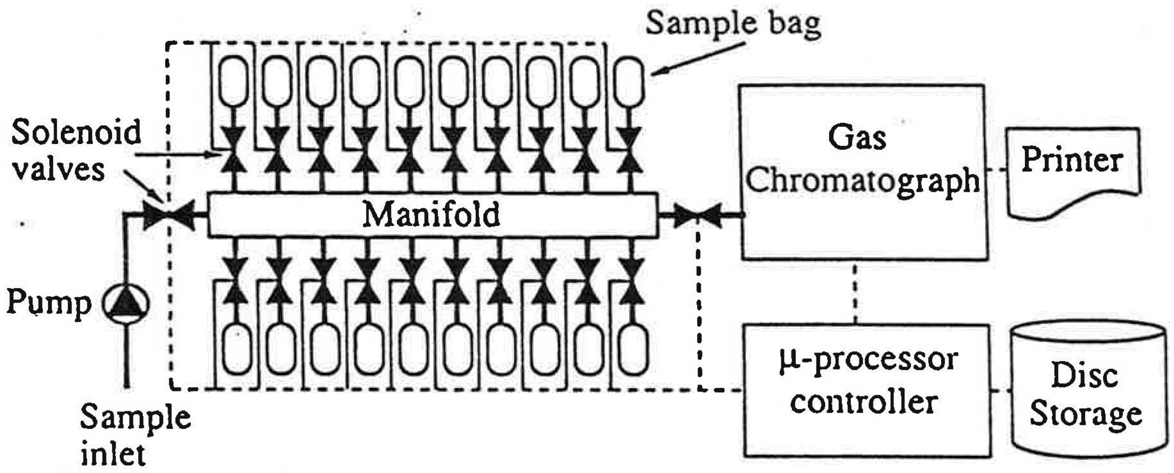
FIGURES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valves
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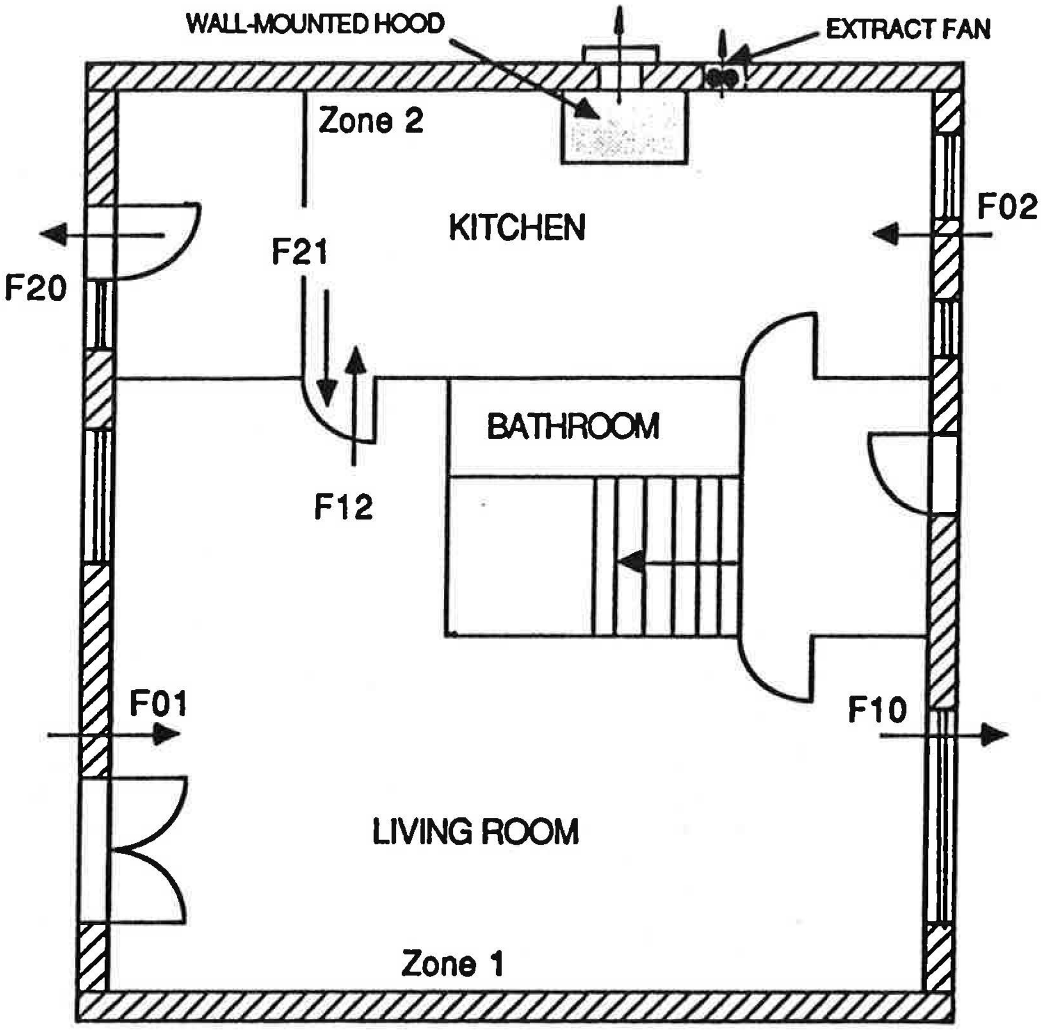
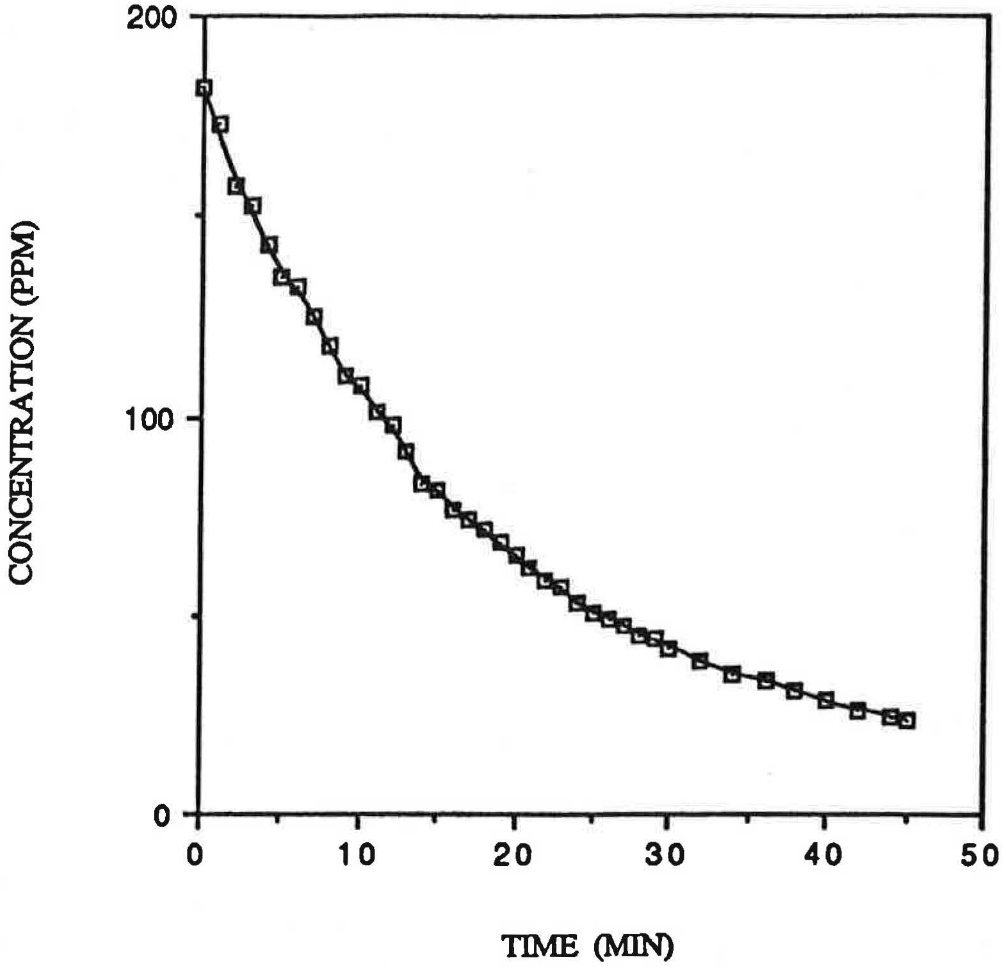
Disc
Storage


WALL-MOUNTED HOOD
EXTRACT FAN
Zone 2
KITCHEN
F02
F20
F21
BATHROOM
F12
F01
F10
LIVING ROOM
Zone 1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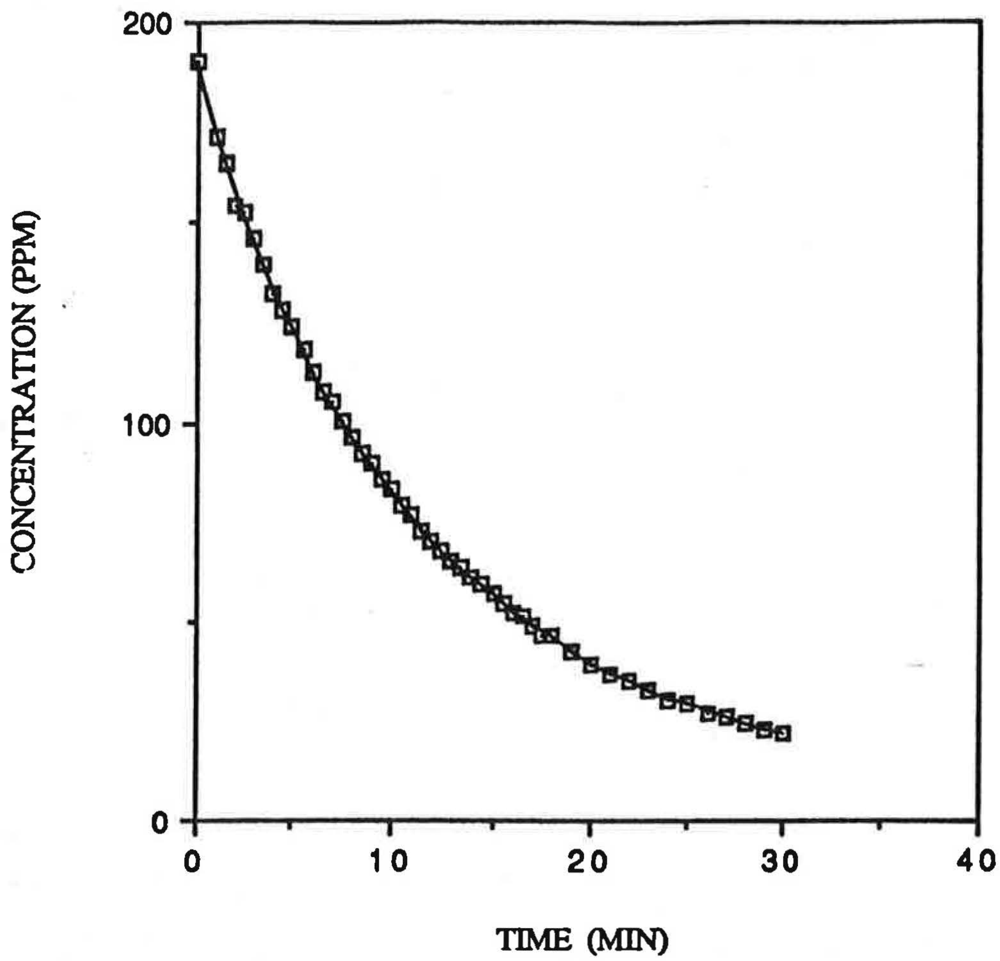

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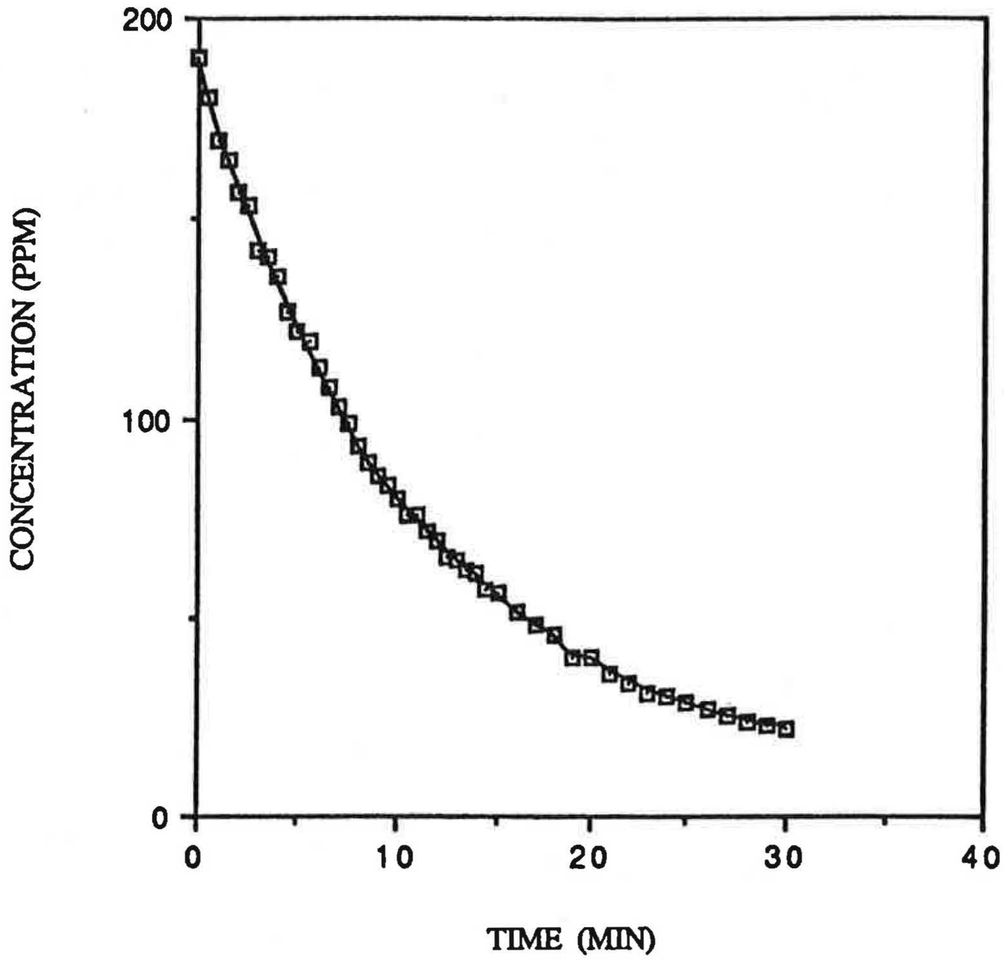
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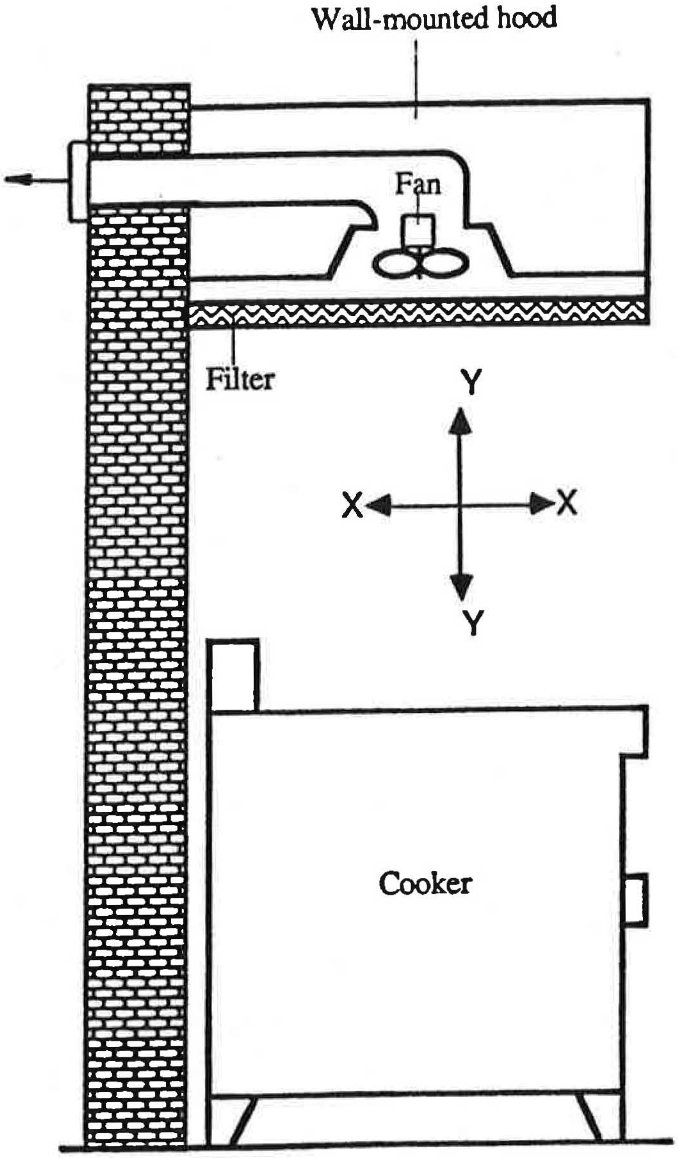

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0.05	0.05	0.06	0.07	0.08	0.10	0.08
0.03	0.04	0.05	0.05	0.07	0.07	0.04
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0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00

Y - Y Plane

0.05	0.04	0.55	0.50	0.05
0.1	0.2	0.25	0.25	0.10
0.10	0.20	0.15	0.12	0.05
0.10	0.10	0.10	0.06	0.06
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0.02	0.01	0.01	0.01	0.01
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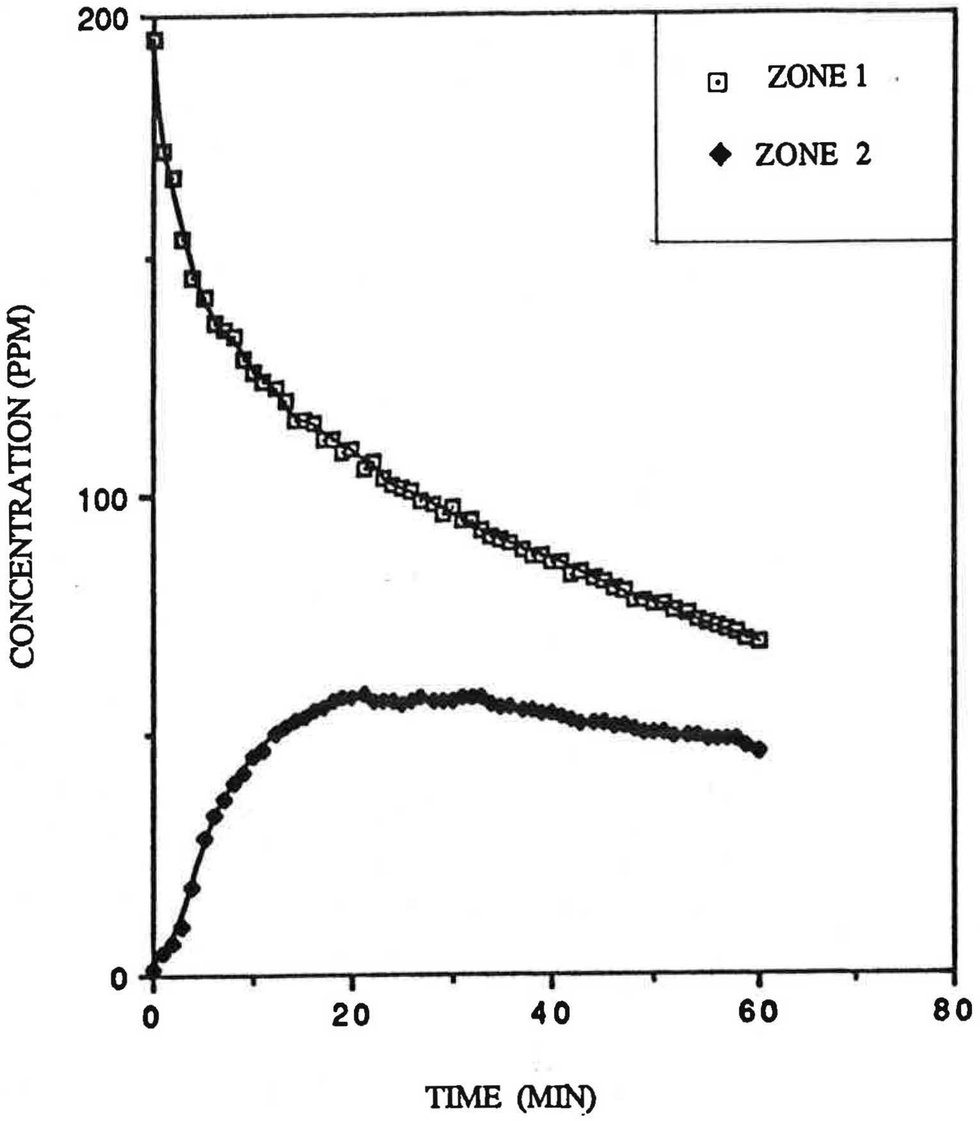

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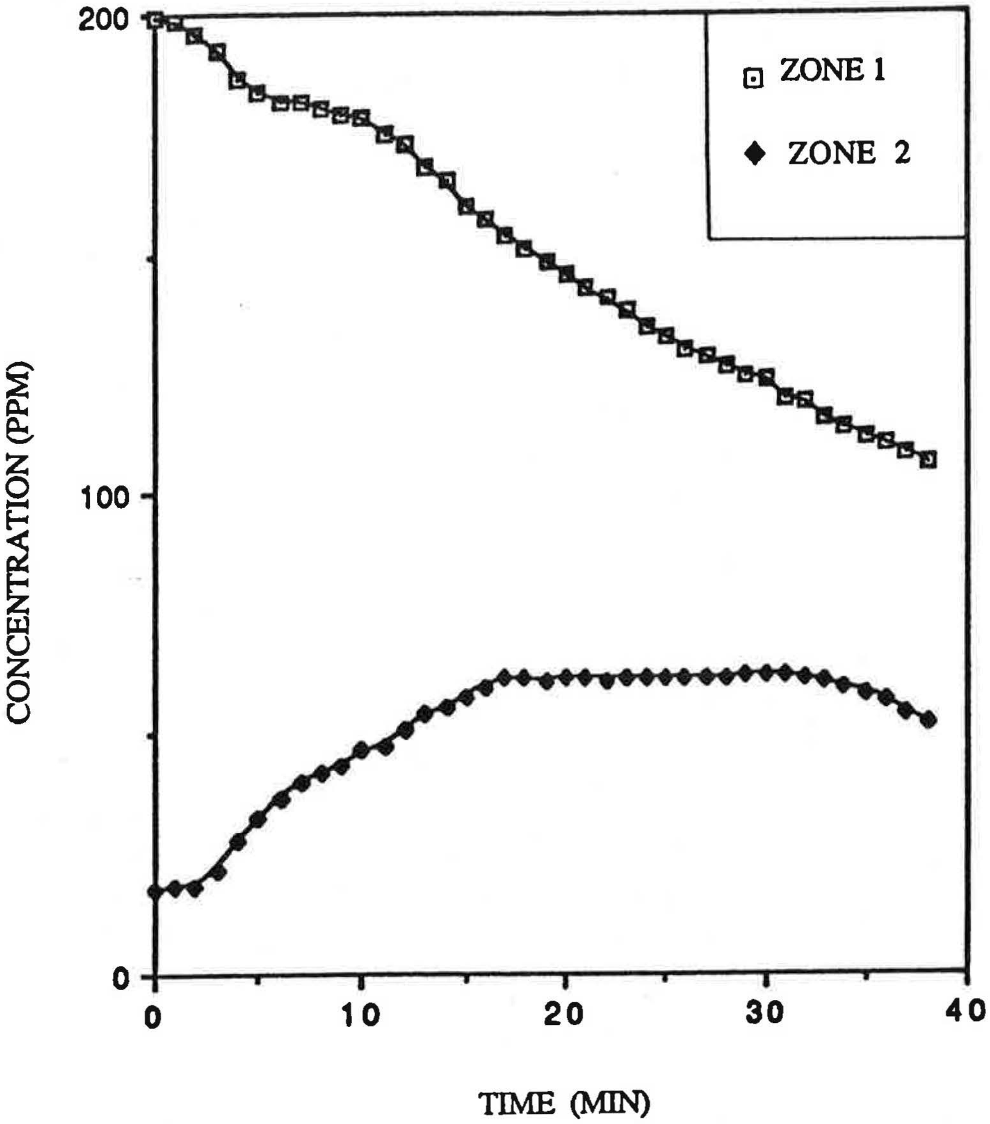
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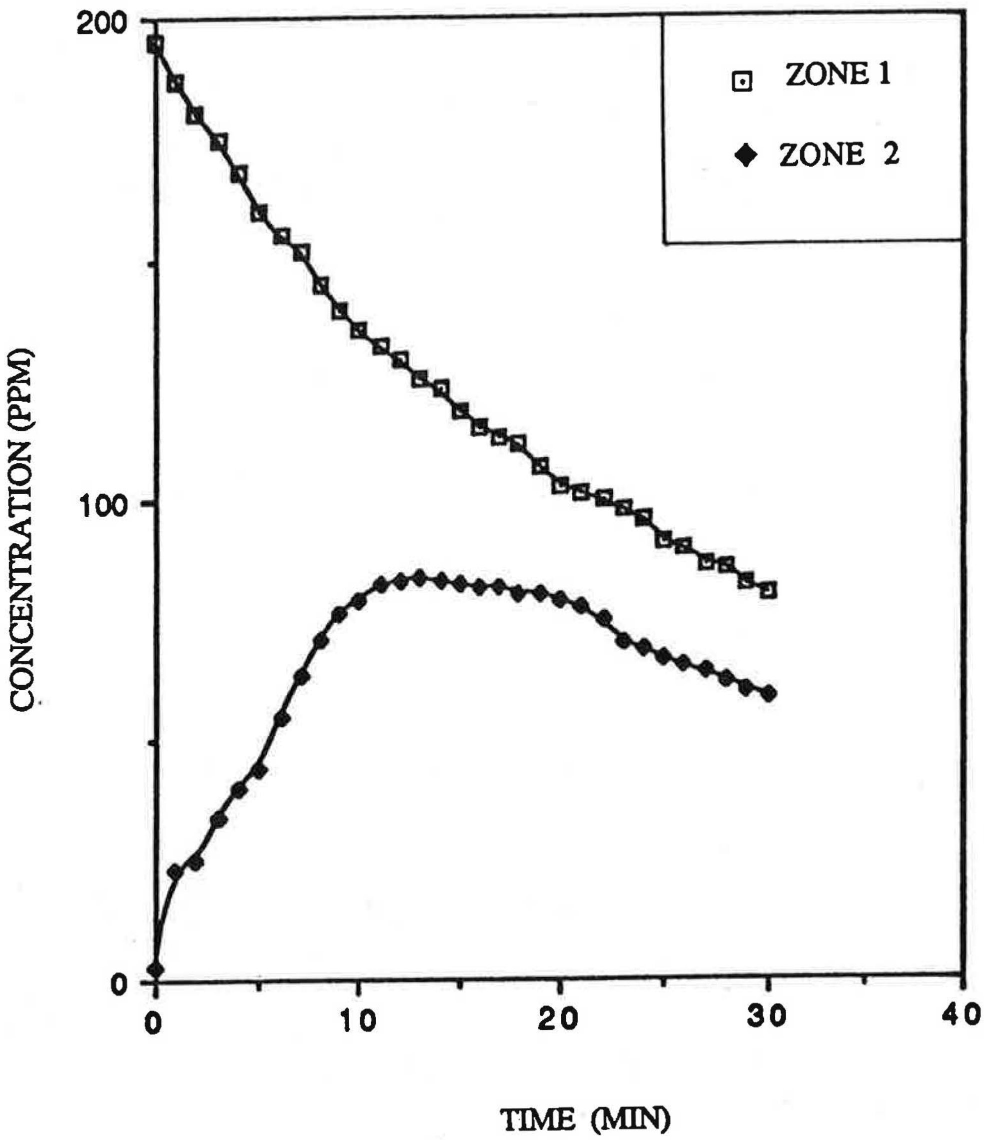
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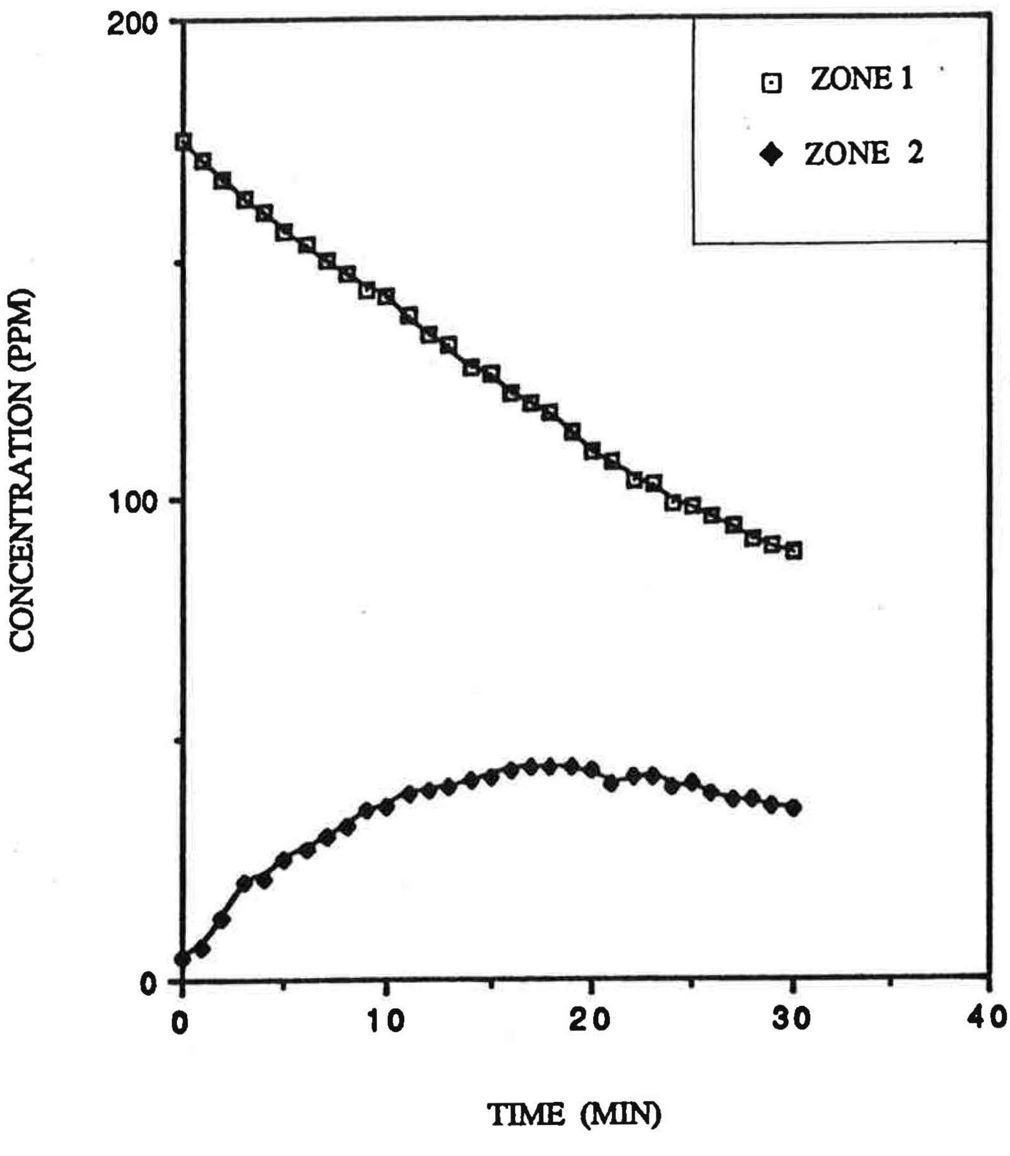

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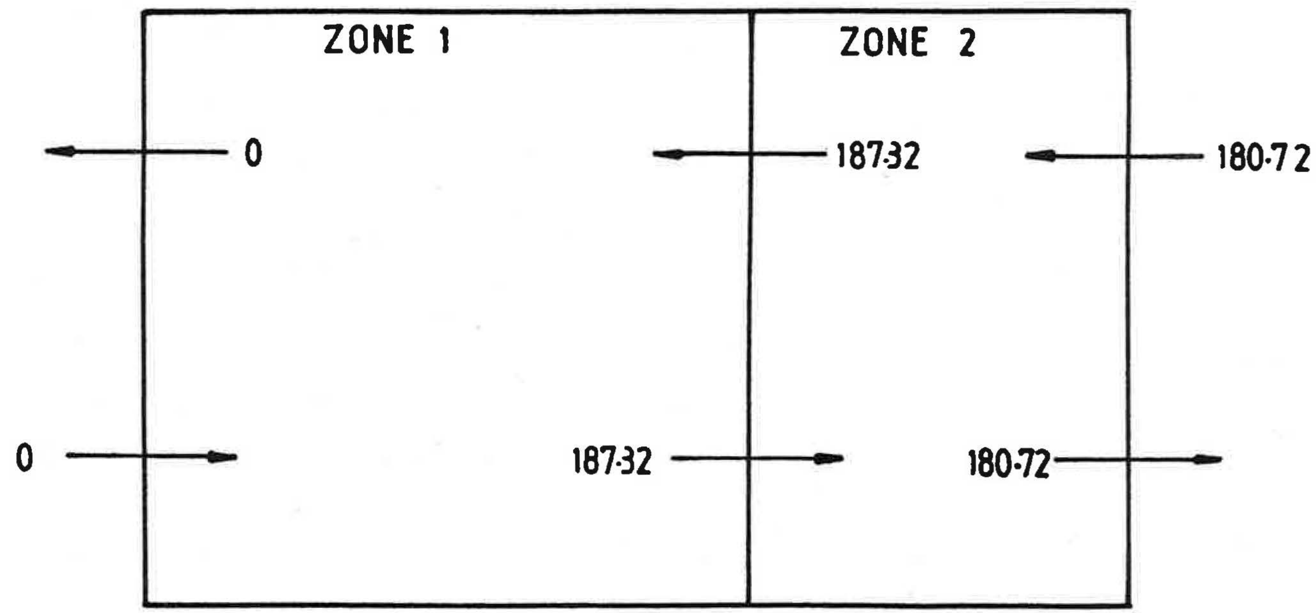
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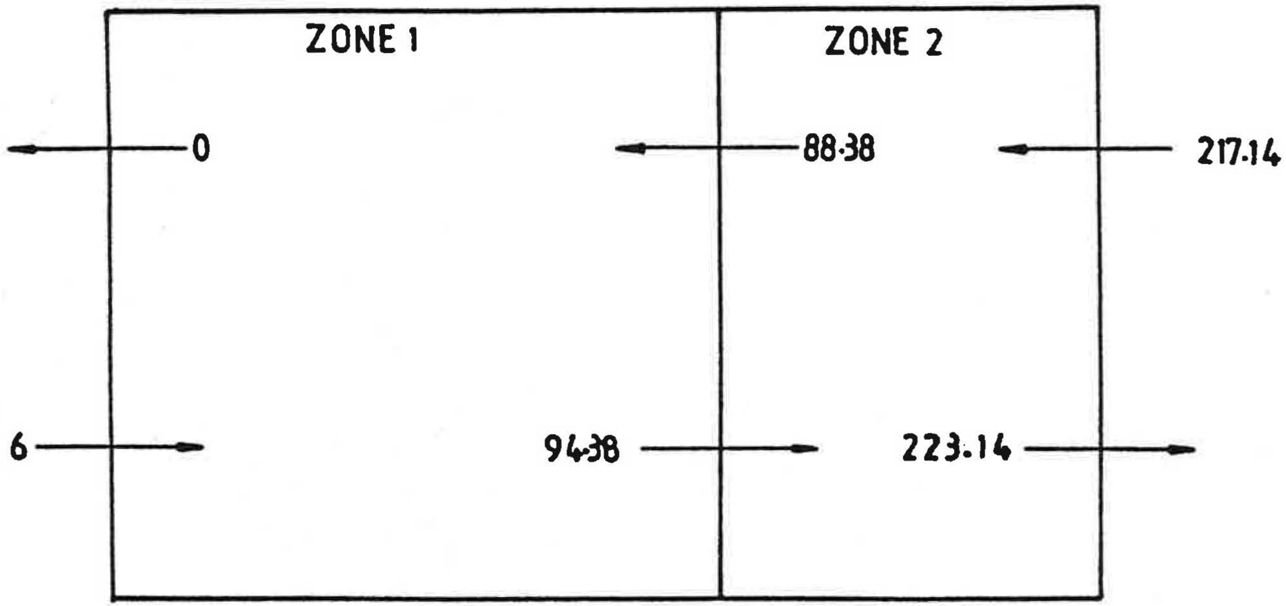
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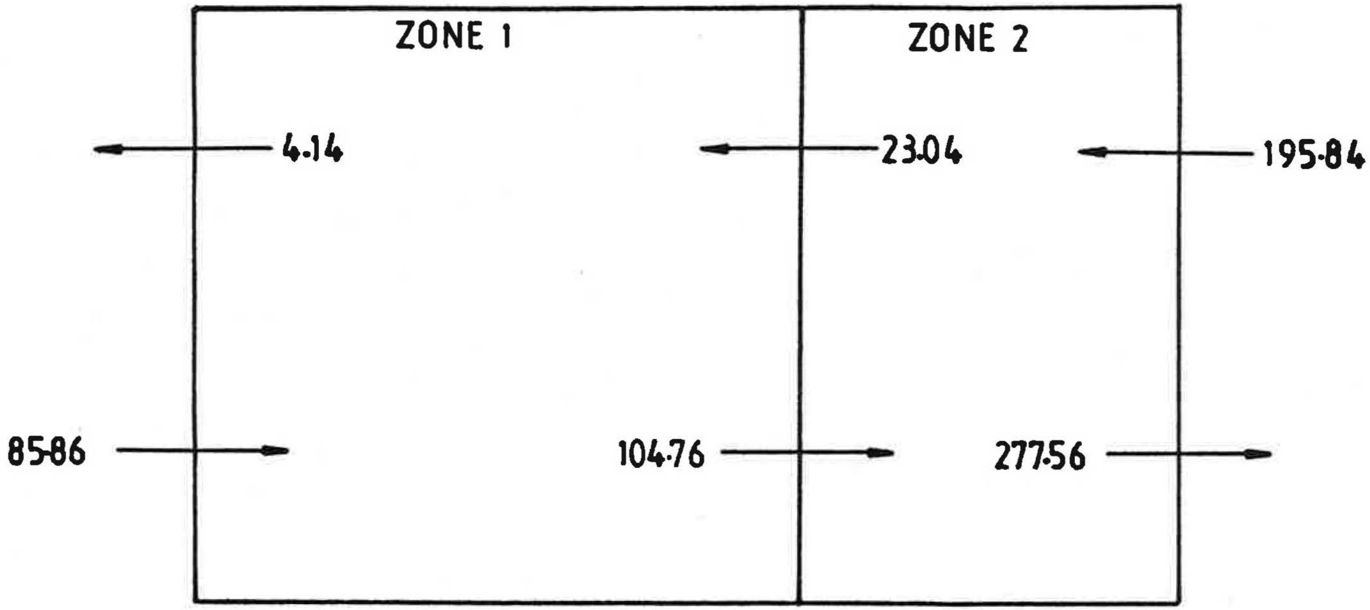
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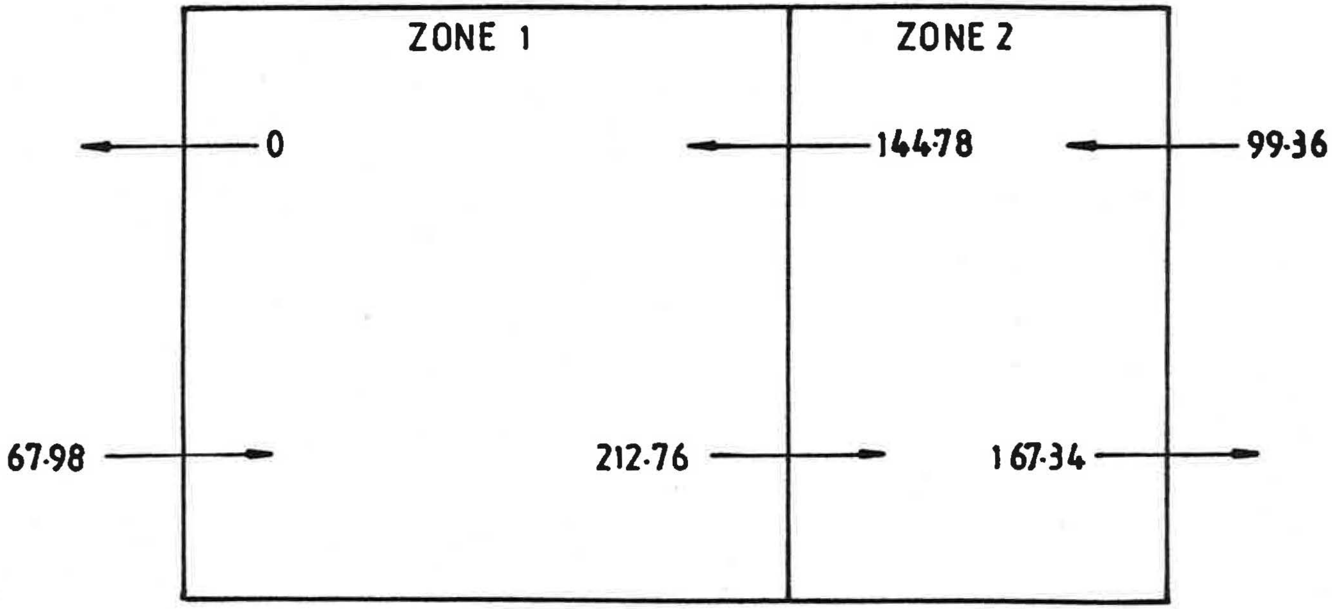
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