This paper examines the impact of such design decisions on the acoustic environment.

PASSIVE SOLAR DESIGN

With approximately 50% of the annual primary energy consumption within the UK being used by buildings it is not surprising that growing concern about the greenhouse effect has given an impetus to energy efficient design. Commercial buildings account for about 30% of this building energy consumption. While a decade ago the emphasis on reducing energy was focused on domestic buildings, commercial buildings have recently been attracting more attention. The principles of passive solar design can be applied to both domestic and commercial buildings though the potential energy savings come in different forms.

In housing, after adequately insulating, siting, differential sizing of windows according to orientation, high performance glazing and the use of pre-heat ventilation from sun spaces (conservatories) have been used in passive solar design.' For commercial buildings it appears that the greatest savings will come from daylight substitution for electric lighting and the use of natural ventilation. Atria have the potential to contribute to energy savings but often do the opposite.

The problems of natural ventilation and summer overheating, especially in offices, are those that are most likely to lead to acoustic problems.

Passive solar housing schemes have so far generally been developed on green-field sites without much traffic noise problem and large natural ventilation rates can consequently be achieved by simply opening windows. If some sound attenuation is required moderate ventilation rates (2-5a.c.h.) may be achieved by staggered opening of secondary glazing systems and others described later. An angled transparent sound reflector at present under development may allow even higher ventilation rates. While dwellings can overheat, often these can be solved by the much greater control and freedom of movement that exists for the individual In such spaces as . opposed to non-domestic buildings.

CRITERIA

In commercial buildings the situation becomes far more complicated. Comfort conditions, thermal, acoustic and lighting, are fairly rigidly laid down for an office. A naturally ventilated space is unlikely to satisfy these criteria all the time. Overheating may occur on some days, noise levels may be high and lighting may be more variable. It is going to be necessary to establish what variability is allowable. There is strong evidence to suggest that people feel better in naturally ventilated buildings. In an early study of building sickness syndrome[1] comparing workers in almost identical air-conditioned and naturally ventilated offices identifiable medical symptoms were much more common in the air-conditioned offices.
Later in a similar study it was reported[2] that an important contributing factor to building sickness was the reduced level of control that individuals have over the environmental conditions when buildings are sealed which heightens the perceptions of discomfort. Griffiths[3] found that the greater variability in temperature in passive solar buildings did not appear to affect thermal comfort and that people did not find such changes unpleasant.

The acoustic environment is one contribution to the total environmental comfort in a space.

Its relative importance in relation to thermal and visual comfort will depend on the nature of the space. The acoustic criteria for offices are laid down for the modern air-conditioning office, with the air conditioning playing an important role in acoustic privacy and the sealed glazing keeping out noise. These are L_{Aeq}*=40-45dB* or L_{Aeq}*45-5OdB*[5] (NR35 or NR40[4]) depending on the type of office and are as much minimum as maximum. While road traffic noise may be intrusive it has already been suggested that people will tolerate higher levels of low frequency sound so that laminated glass can be used in fast track construction. To what extent these levels can be increased to allow natural ventilation where intrusive road traffic noise exists is a matter for the total comfort sensation of the office as a whole. But are there limits?
Maximum intrusive noise levels to allow normal speech conversation are L_{Aeq}*=51dB* at 2m and L_{Aeq}*=57dB* at 1m.[5] Telephone conversations are satisfactory at 58dBA or NR5O, slightly difficult at 68dBA or NR60.[4] Perhaps an absolute maximum could be set at L_{Aeq}*55-60dB*?
These may describe the upper limits for noise within the office but there is still a need for a minimum. Sound masking systems fulfill this function adequately at the moment but it is sometimes difficult to persuade a client demanding a 'green' 'healthy' building that electronically created noise is necessary.

SOUND ABSORPTION AND THERMAL MASS

Without air-conditioning the passive solar building loses the need for a ceiling void behind acoustic tiles with the minimal services supplied in a small raised floor. Acoustic control is still needed but application of acoustic treatments in the form of a suspended ceiling or by direct attachment to the ceiling creates thermal insulation between the air and the ceiling. mass is an important element in the design of naturally ventilated buildings as it helps to prevent overheating. Access to the floor slab is prevented with a raised floor and/or carpets so the ceiling needs to be exposed.

It has been reported[6] that an exposed ceiling will reduce the room temperature on a warm day by 1-2°C or that the internal heat load can be increased by 5-10W/m^2. This can be maintained over a long. period by night-time ventilation.
The effect is almost maintained if a suspended ceiling is in place with 11% of the tiles removed in strips. The consequences on reverberation time of the room is marginal but there will be increased problems of room to room transmission. Physical barriers above partitions may be the only solution as acoustic treatment of the underside of the floor slab will act against providing thermal mass. These barriers are not easy to implement if the void carries services[7,8].

The role of the convection currents set up in the void is obviously very important and a similar thermal performance could not be expected from the use of directly attached tiles or from a shallow void designed to satisfy the lighting requirements. No data is available although suggestions are being made (though not in print!) that for directly attached tiles about 80% of the ceiling area needs to be exposed. There must be doubts about this area of tiles being acoustically satisfactory. At the moment a voidless ceiling is only likely to be aesthetically compatible with an uplighting system. These systems use high pressure sodium and metal halide discharge lamps which are not yet compatible with daylight substitution electric light controls and therefore not suited to daylit buildings.
open grid ceilings will fulfill the requirement for access to thermal mass but the incorporation of the acoustic absorber needs careful consideration. Vertical acoustic elements (akin to the