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Heather J. Robertson

School of Architecture,
The Royal Institute of Technology,
Stockholm, Sweden

Built Form and Health

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Abstract
Links between buildings and human health were made through characterizing the physical forms of a group of 'complaint' buildings. A study was made of 40 Australian dwellings in which occupants reported continuing hypersensitivity symptoms. Spatial factors from floor and site plans were examined in order to investigate why complaint was associated with leeside rooms. Over-represented factors that could not be explained by planning conventions were identified and then compared in subgroups. Mechanisms by which built form could influence occupant exposure to indoor pollutants, such as under-ventilation, moisture transfer or microbial growth were considered. Of nine spatial factors tested, five showed marked irregularity. Two of these, bathroom orientation and bathroom location in relation to the bedroom of the most sensitive person, appeared to be the most important. Findings indicated that, in most of the cases, chronic hypersensitivity symptoms could have been linked with regular exposure to a pollutant carried on airflow from bathrooms. The study has demonstrated a way of using spatial factors as variables in investigations of health and the built environment. It also has raised the possibility of recognizing some types of problem buildings by their forms.

Introduction

When characterizing a group of problem buildings, factos such as symptom prevalence, levels of airborne chemicals, and construction types and materials usually come to mind first. This paper presents another approach, exploring links between reports of persistent hypersensitivity symptoms and measurable spatial qualities of the built environment. The approach was based on the proposal that built form may influence dispersion of indoor air pollutants consistently over time, and therefore could serve as a broad predictor for exposures in occupied buildings.

The approach was developed following a broadly based study of problem dwellings in southeast Australia during the 1980s, in which a wide range of information was gathered through on-site interviews and visual inspections. The initial analysis [1] showed that health complaints were linked with rooms having all opening-windows towards the most likely leeward directions. A second analysis of built form, based on floor and site plans of 40 dwellings, has been presented in this paper. The analytical method was devised to test a microbiologist's proposal that indoor moisture generation was contributing to adverse health effects. The objectives were:

(1) to better understand the nature of a possible health effect linked with the case study housing, and

(2) to test the effectiveness of using spatial factors in characterizing a possible problem building type.

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Heather J. Robertson
The School of Architecture
The Royal Institute of Technology
S-100 44 Stockholm (Sweden)

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Background of the Study

The housing study [1, 2] included all households whose members had approached the author for architectural advice on housing for environmentally sensitive occupants, where a site visit to the existing home environment was subsequently made. In each household, one person was identified as most in need of a 'safe' home environment free of specific indoor pollutants. Health problems were sometimes described as 'chemical allergy', and were often attributed to causes other than the building itself, such as poor work environments, accidents or an inherited predisposition to allergy. Most participants had been referred by an allergist or allergy association, and had considered changes to the dwelling only after trying many other therapies, usually for a year or more.

The allergist's proposal that symptoms were intensified by the home environment was in many cases supported by the investigating architect's observations during site visits. Sometimes basic building faults, such as misdirected storm water, were present. Often, several household members reported similar symptoms to the sensitive person, although these were usually less severe. Further, the investigating architect experienced symptoms in some dwellings, as did two other architects on several occasions. The resident with a need for special consideration has been called the 'target person', and the term 'target room' has been used to indicate the room of a dwelling which was reported as 'worst' by residents, or, as in the majority of dwellings where no such distinction was made, the bedroom of the target person.

The present investigation arose from an early observation that target rooms very often faced northward, which contradicted conventional wisdom that sunny rooms were ideal for allergic persons. Householders often asked for similarly oriented bedrooms in new housing. Mostly, however, they gave priority to remedial measures based on choice of heating fuels and building materials, naming specific chemicals to be avoided.

The dwellings were in many ways typical of the Australian housing stock, most being owner-occupied, single storey, detached houses. Mainly they had elevated, uninsulated floors, timber frames and brick external cladding, but some had lightweight cladding and others were solid brick. Most had been built between 1920 and 1982, with about one third before 1960. Typically, the size of the plots allowed windows in all walls. While no two floor plans were alike, most dwellings had 3 or 4 bedrooms, a separate laundry, and 1 or 2 bathrooms with showers. Almost all buildings had a variety of fixed vents to cavities of external walls in each room. Laundries, kitchens and bathrooms had either passive ceiling vents or intermittently used, unshuttered exhaust fans, usually opening into the roof space.

Although a few dwellings were small, the sample could generally be described as being somewhat above average in standard, well-presented and with care taken in household management. There were no unflued heaters of any kind, a very low frequency of occupants who smoked and relatively few gas cooking stoves. However, readily observed dampness problems, such as those from inadequately collected storm water, were frequent [2].

The association of complaint with occupancy of lee-side rooms suggested a link with indoor airflow. This possibility was supported by the fact that many of the modifications already made by householders in order to make the dwelling 'healthier' would have tended to reduce both whole-house and room ventilation rates, e.g. a reduction of heating levels, the closing off of 'safe' rooms where pollution sources had been minimized, and the non-use of ducted heating systems.

Most dwellings were in or near Melbourne. All were between latitudes of 45 and 30°S, in a temperate climate, with rainfall throughout the year and much of it in winter [3]. Mean daily minimum temperatures for all months were between +5 and +15 °C [1]. Ventilation characteristics of typical housing in this region have been only minimally researched [4], probably because of the mild climate and the assumption that such buildings would tend to be over-ventilated. In a study of 7 typical Melbourne houses, Biggs et al. [5] found that whole-house ventilation was almost entirely wind dominated. Air change rates correlated well with wind speeds taken from regional weather data, after allowing for wind direction sensitivity in 4 of the houses. Health effects associated with the 40 dwellings might have been related to similar wind direction effects, which could be indicated by spatial characteristics of whole buildings and sites, as well as of rooms.

Evolution of the Testing Method

The group of 43 problem buildings initially studied [1] was reduced to 40, in order to exclude 1 building that was not a dwelling and 2 dwellings occupied for several weeks only. The minimum occupancy time was 3 months, because this was the shortest time where a complaint was associated clearly with the dwelling, by the householder having sealed off a disused bedroom. The length of occupancy of dwellings and symptoms of target persons were noted in open interviews, with a parent responding when the affected person was a child. Gender and approximate age of each target person were noted.

Site and floor plans of the 40 dwellings were studied in an attempt to identify any predominant spatial characteristics, especially those which could enhance pollutant levels in rooms frequently occupied by target persons. In occupied houses, a variety of door and window opening patterns was likely, and possible wind-influenced effects might have included either under-ventilation or moisture or pollutant deposition in leeside rooms. Three spatial indicators for such effects were suggested by Dutch and German research:

(1) reduced ventilation of any room when there was a larger opening to another room on the same façade [6];

(2) under-ventilation of leeside rooms with closed internal doors [7]; or

(3) transfer of moisture from windward wet rooms to leeward rooms [8].

A fourth possibility was insufficient whole-house airflow where the floor plan or external sheltering reduced the influence of prevailing winds, as suggested by unpublished data from the Australian study of 7 houses.

Characteristics specific to multi-story housing, such as under-ventilation of lower floors [9] and deposition of moisture according to stair layout [10] were not included due to the relatively few dwellings with internal stairs in the sample studied. The findings of De Gids and Phaff [11], showing increased exposure to indoor pollutants in leeside bedrooms in Dutch apartments, were considered relevant, however, the bedrooms were upstairs in both houses studied, a factor reported to increase the lee effect in dwellings [9].

Method

For the buildings, wall orientations were classified into eight directions to match meteorological records. Factors related to compass orientation were recorded from floor and site plans. These were presented in diagram form for the 40 dwellings, generally by using an eight-armed star shape, with a dotted circle indicating the average value for all directions. The patterns arising were examined for unusual characteristics. Where a factor appeared to be over-represented in the group as a whole, its frequency in subgroups was compared. Generally, two subgroups of comparable size were used. The subgroups were defined by contrasting design characteristics within the group of 40 dwellings, mostly related to target rooms.

Ten factors arising from interviews and visual records were used in the analysis. They were as follows:

Occupancy and Symptoms. Volunteered symptom reports were classified into six broad categories; hypersensitivity, bronchial complaints, asthma, skin complaints, fatigue and other (including headache and mood change). A seventh symptom, 'loss of sense of smell', was included as question during the course of the investigations, because it was found that participants did not usually volunteer such information. For each dwelling, the prevalence of similar symptoms reported by other occupants, and also by three visiting architects, was compared.

Building Walls. The orientation of building walls to cardinal sectors was determined. A basic distribution of wall orientation was then estimated for two sectors: the likely leeside at 3 p.m. for the Melbourne region, as previously defined [1], and the five directions which faced away from the cool season sun, hereafter referred to as 'leeward' and 'least sunny', respectively.

Bedrooms and Target Rooms. The orientations of walls in all bedrooms which had opening windows were compared with those of target rooms, because in all but 1 case, the target room was a bedroom. A leeward target room was defined by having all opening windows to the leeward zone, while a windward target room needed only to have 1 opening window to the windward zone. Sheltering of windows by physical barriers ≤ 3 m from room openings, such as wing walls, cut banks and fences over sill height, was noted for both windward and leeward target rooms. However, foliage close to walls was not included, as it was present in nearly all cases. Sheltering information was taken mainly from plans drawn on site.

Streets. Directions of adjoining access streets or common driveways relative to the dwelling were recorded, because vehicle access might have influenced room layout.

Living Rooms. Orientations of living room walls with collective window widths > 2 m were indicated, regardless of shading provisions. Living rooms large enough for uses other than dining were included, and windows to kitchen areas omitted.

External Main Doors. Orientation of main-entry swing doors was recorded because they were more likely than other external openings to lead into central circulation spaces and influence internal air movement. It was assumed that even closed doors might contribute significantly to air infiltration, as found by Biggs et al. [4, 5].

Bathrooms. Window orientation of all rooms with showers was recorded. Bathrooms opening directly off target rooms were noted.

Target Rooms According to Bathroom Orientation. The orientations of target rooms in dwellings with at least 1 windward bathroom were compared with those having only leeward bathrooms.

Topography. Estimates of site slopes were made by observing relative heights of site corners or of subfloor walls where the natural ground level had been retained. From these data, a diagram of downhill site slope directions was constructed to provide an indication of local topography.

Sensitivity to Prevailing Winds. The number of window and door openings on the wall closest to west or southwest was compared with the total for all other wall orientations for each dwelling. These walls faced to middle of the half sector designated as windward. Sensitivity to prevailing winds was expressed numerically, with 0.33 representing a ratio of 1:3 for west or southwest to all other openings. For different subgroups, the percentage of dwellings with a low ratio, i.e. < 0.3, was compared.

Results

Occupancy and Symptoms. Six of the dwellings had been occupied by the target person for a period of 3 months to 2 years, with all other dwellings occupied longer (2–19 years). Of the 40 target persons, there were 23 women, 6 men, 6 girls and 5 boys. The symptoms recorded are in table 1.

Seven dwellings had only 1 occupant, and the remaining households had 2–7 persons. In 25 of the 33 households, at least 1 other occupant reported similar symptoms to the target person, typically less severe. In 23 of the 40 dwellings, a visiting architect also reported symptoms within 10 min to 3 h from entering, with symptoms disappearing soon after leaving the building. Mostly such symptoms were at a discomfort level, and it was not seen as necessary to leave a room or building prematurely. In 5 cases, however, severe discomfort (such as a burning windpipe, nausea, extreme lethargy or a major headache) was such that it was necessary to leave a specific room within minutes. In these cases, the sensitive person was also present, but appeared to experience less discomfort.

Usually, visitors reported different symptoms from occupants (e.g. short-term bronchial irritation rather than asthma or allergy). Skin complaints were less frequent and of shorter duration in visitors than in occupants, being noted only twice, and in both cases, disturbed mineral fiber insulation had not been isolated from indoor spaces. In general, visitors' symptoms were mild irritations, such as nasal congestion and dry or sore throat, which increased gradually with time spent in the building. Most time was spent in living rooms or kitchens during visits, not necessarily the rooms most often occupied by target persons.

Building Walls. Twenty-three buildings had walls facing cardinal sectors, and 2 buildings had both cardinal and noncardinal wall alignments. Thus, the 40 dwellings had a basic wall distribution pattern of 60% to cardinal, 50% to leeward and 65% to the least-sunny sectors.

Bedrooms and Target Rooms. These two factors have been considered together because in all but 1 case, the target room was a bedroom. In the 40 dwellings, 145 rooms were being used, or had been planned for use, as bedrooms. Sixteen of these rooms had opening windows in more than 1 wall. Figure 2 shows that the total number of such window-wall orientations was 86 leeward (29 of these were for target rooms) and 76 windward (15 were for target rooms).

Twenty-five target rooms had opening windows oriented leeward only. In 9 of these rooms, the opening windows were sheltered. There were 15 target rooms with at least 1 windward opening window with 7 having sheltered, and 8 had relatively unsheltered window walls. The subgroup of 32 leeward and sheltered target rooms is shown in figure 2.

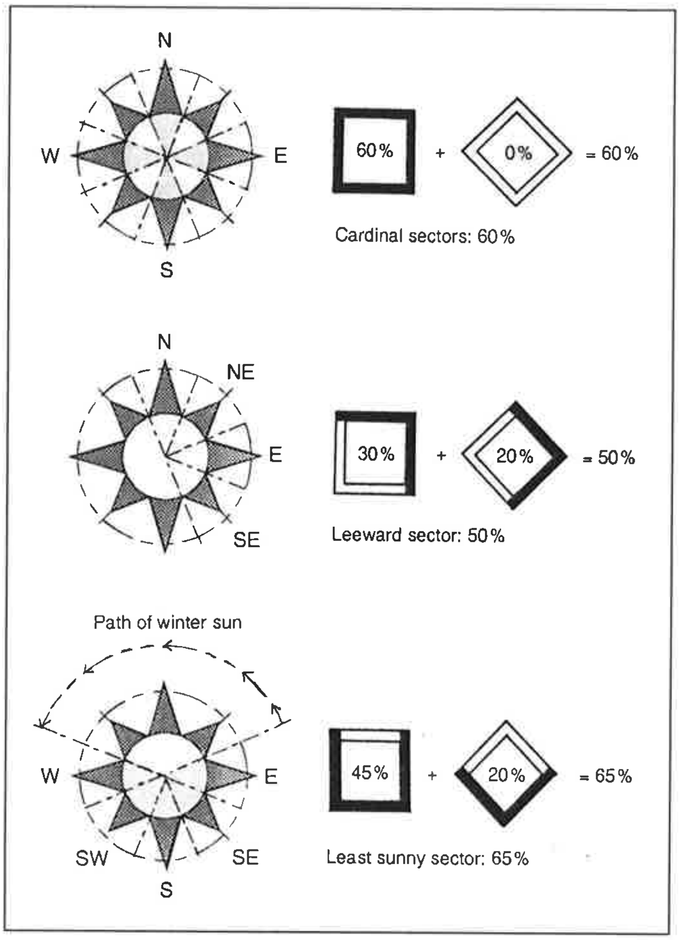

Fig. 1. Building walls: basic orientation pattern.

The proportion of target room orientations to those of all bedrooms for each of the eight directions is shown in figure 3. It can be seen that the most prevalent target room orientations were the four corresponding to the 'likely leeside' directions derived from the meteorological data. North did not have the highest value relative to the large number of north bedrooms in the entire sample group.

Streets. The orientations of vehicle access routes relative to dwellings, which in most cases corresponded to front façades, is shown in figure 4. Most alignments were to cardinal sectors. Leeward (50%) and least-sunny (65%) sectors exactly matched the basic wall pattern (fig. 1).

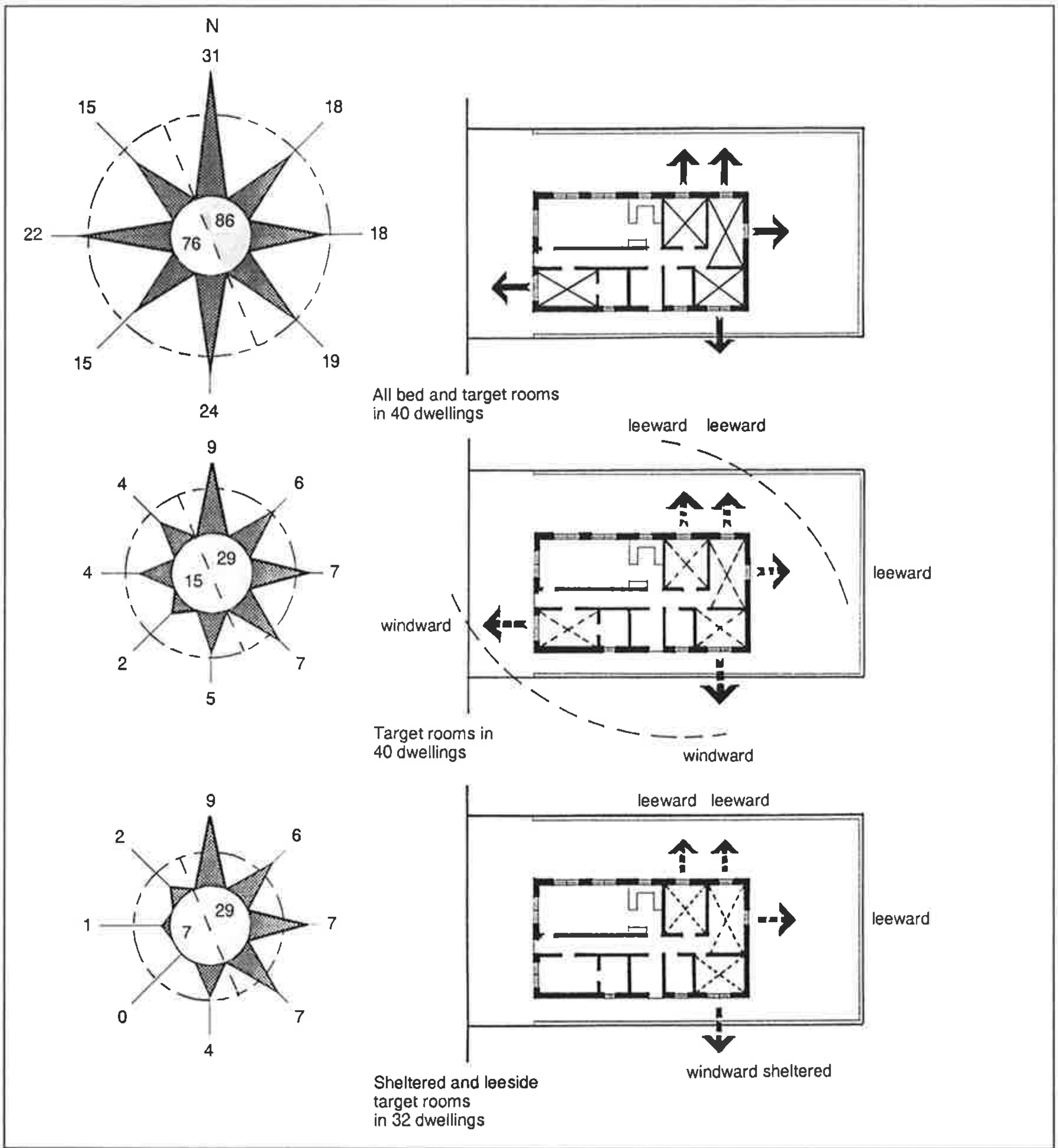

Fig. 2. Bedrooms: orientation of opening windows.

Table 1. Symptoms of target persons and visiting architects

Reported symptoms	Target person (in 40 dwellings)	Visiting architect (in 23 dwellings)
Hypersensitivity or allergy	39	0
Bronchial complaints (sinus, cough, hayfever, including asthma)	16	15
Asthma	8	0
Loss of sense of smell[1]	9	0
Skin complaints (eczema, itching, inflammation)	7	2
Fatigue	18	8
Other (including headache, hyperactivity, mood change)	22	8

[1] May be under-reported as this question was not asked in all cases.

Living Rooms. Figure 5 shows the orientation of living room walls with collective window widths > 2 m in the 40 dwellings. Generally, there was no marked trend away from the basic wall or street orientation patterns, with 62% to cardinal, 56% to leeward and 61% to the least-sunny sectors.

External Main Doors. The main (front) door orientations of 40 dwellings (fig. 6) shows a similar overall pattern to the walls, street and living room diagrams. Orientations showed a slight bias to the windward sector, which was not apparent (fig. 6) if the 8 houses with unsheltered windward target rooms were omitted. Of these 8 houses, only 1 had a leeward front door (fig. 6). This house was of an unusual layout in that it had 5 external swing doors to the windward rear garden, 1 of them opening into the same central circulation space as the leeward front door. Thus all 8 layouts supported the under-ventilation of windward rooms due to larger infiltration areas in the same façade.

Bathrooms. Most bathrooms were used daily for showering. Relatively few households with more than 1 bathroom left any unused, so all bathrooms have been considered. Seven bathrooms which had only ventilated skylights have not been indicated in the diagrams. The other 58 bathrooms in the 40 dwellings had 1 window each, oriented as shown in figure 7. More bathroom windows faced windward (62%), and many (81%) faced away from

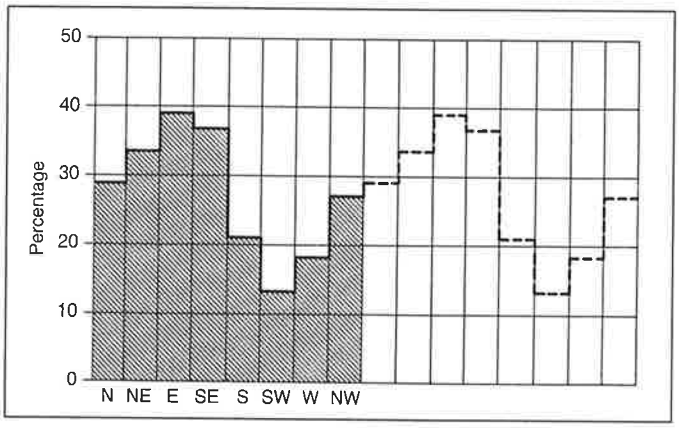

Fig. 3. Percentage of all bedroom orientations which were target rooms, for 8 compass directions.

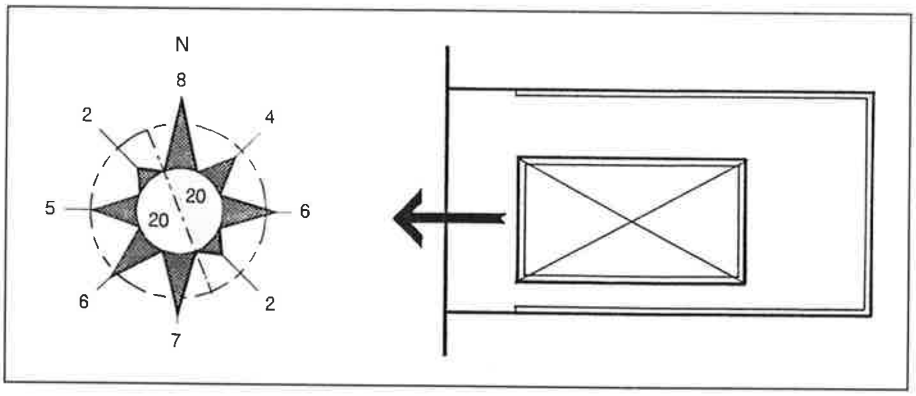

Fig. 4. Street orientations. Direction of main vehicle access from each of the 40 dwellings.

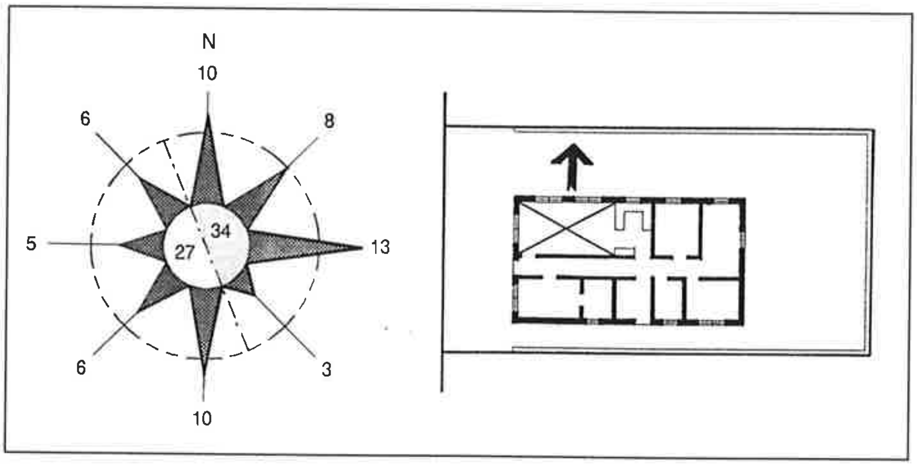

Fig. 5. Living room orientations. Orientation of walls with glazing wider than 2 m, for 40 dwellings.

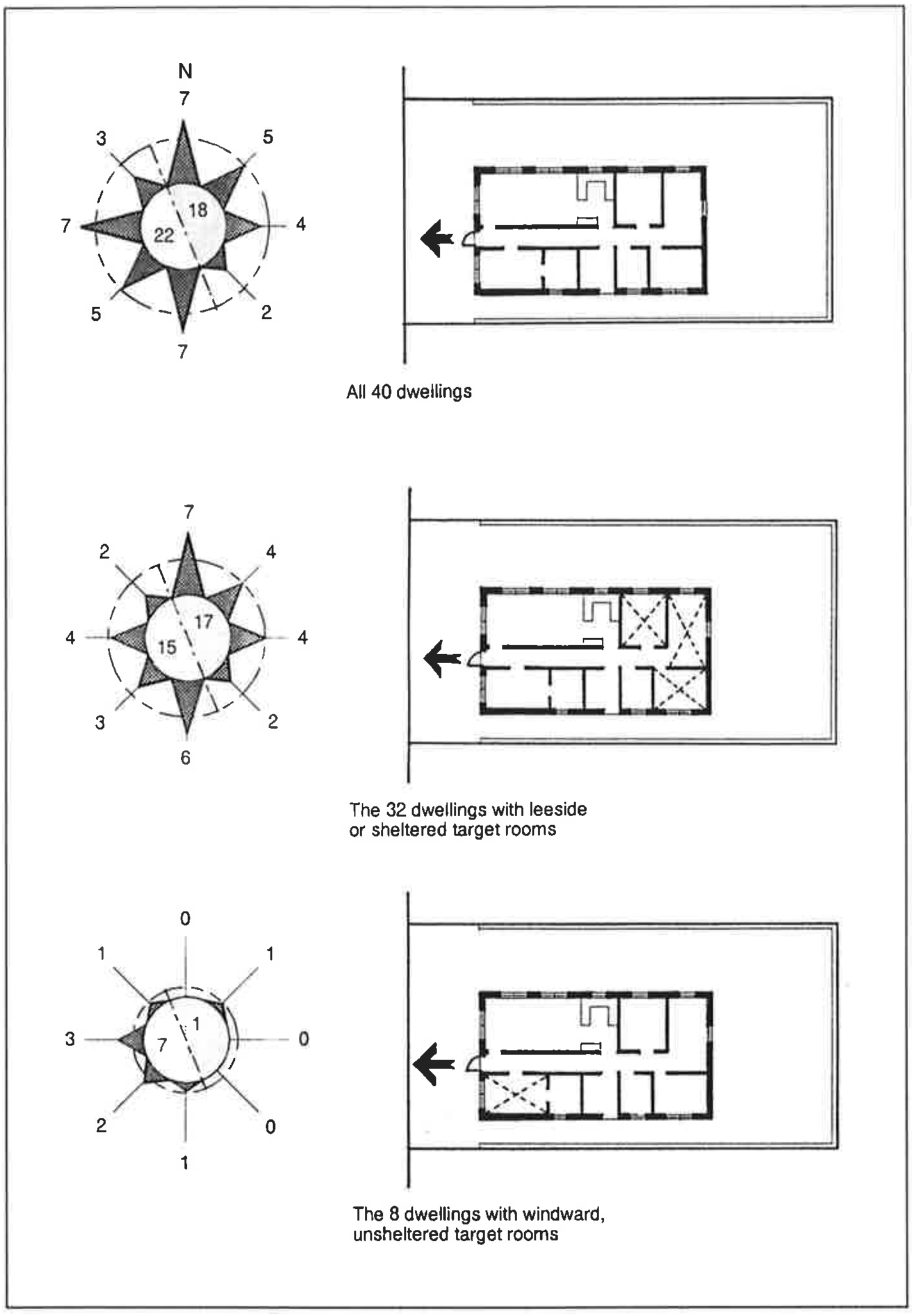

Fig. 6. Orientation of main external swing doors (front doors).

the cool season sun. Both values were higher than the expected 50 and 65% from the basic wall orientation pattern (fig. 1).

When one considered only the 22 dwellings with leeside or sheltered target rooms and no attached bathrooms, both values were even higher. For this sub-group (fig. 7), 86% of bathroom windows were windward, with 96% facing the least-sunny sector. In the other subgroup of 18 dwellings, windward bathroom orientation was not apparent, nor was the prevalence of sunless orientations. A bathroom opened directly off 15 of the 18 target rooms, which suggests frequent exchange of air between bathroom and bedroom irrespective of room orientations. There was a high proportion of southeast bathroom windows, i.e. towards the 'least-sunny and most-windless' of the eight aspects, which could be expected to stay damp longest without extra heating and ventilation. Five of the 8 unsheltered windward target rooms had attached bath-

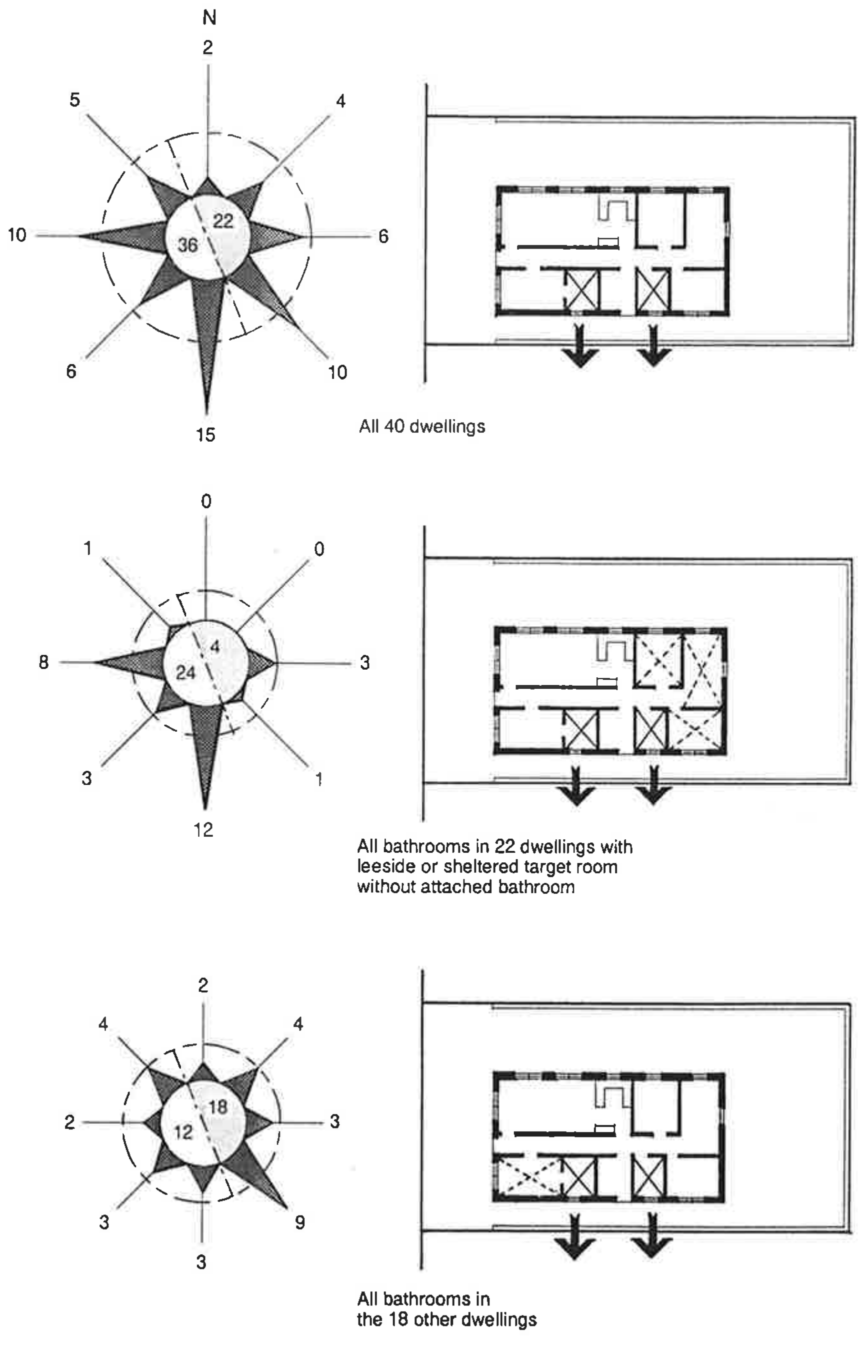

Fig. 7. Orientation of bathroom windows.

rooms, 2 facing southeast, and one each to south and east. The 5th was in the only house to have north-facing bathrooms, and was unusual in that it was being used by 6 people daily, each showering for about half an hour.

Target Rooms According to Bathroom Orientation. If a health effect were associated with sunless or windward bathrooms, even 1 such bathroom per dwelling could contribute. There was at least 1 sunless bathroom in 36 dwellings, and at least 1 windward bathroom in 27 of the dwellings. In figure 8 the target room distribution for the 27 dwellings has been compared with that of the other 13 dwellings. The larger subgroup showed a strong bias to the

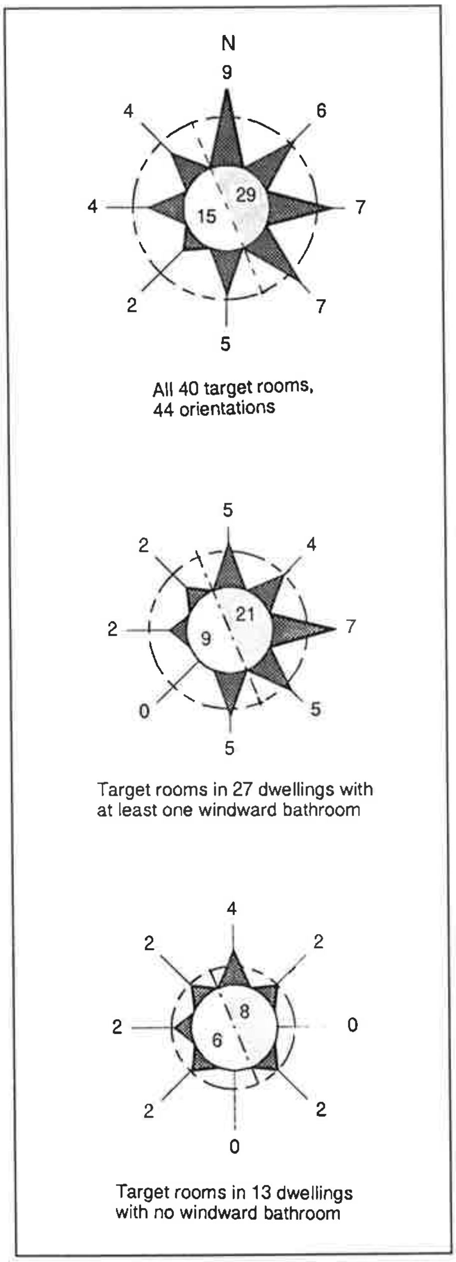

Fig. 8. Target room orientations according to bathroom orientation.

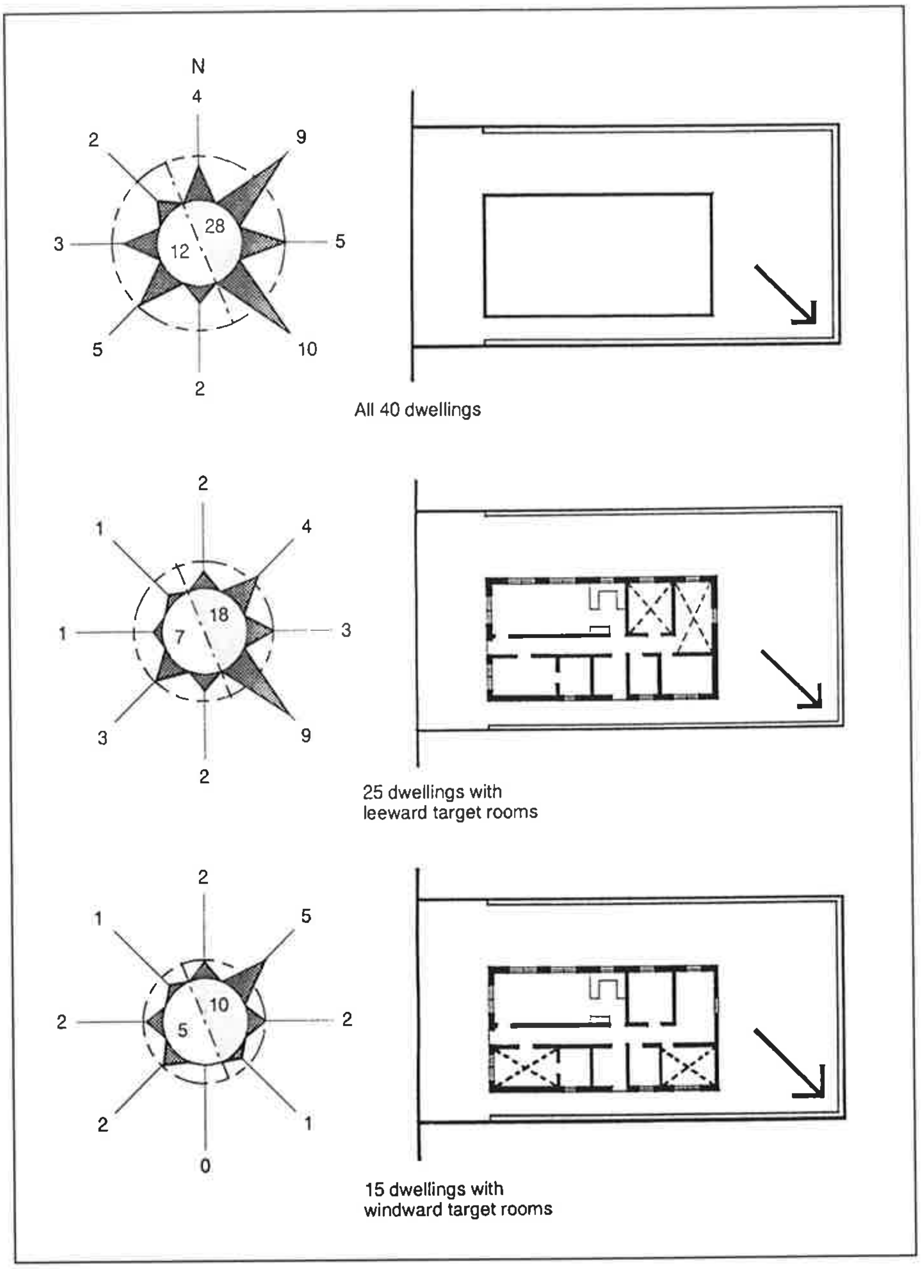

Fig. 9. Direction of downhill site slopes.

easterly half of the compass, a bias which was not at all apparent in the smaller subgroup. Thus the initially observed link between leeward-oriented rooms and health complaints could have been due to airflow from windward bathrooms, regardless of whether the bathroom was attached to, or distant from, the target room.

Topography. Figure 9 shows the direction of downhill slopes recorded for each site. Assuming these were indicative of the broader topography, a tendency for housing to be located on leeward slopes was apparent for the group as a whole (70%). The 25 dwellings with leeward target rooms tended to have southeast sloping sites. The 15 dwellings with windward target rooms had more northeast sloping sites, which may have been most windshel-

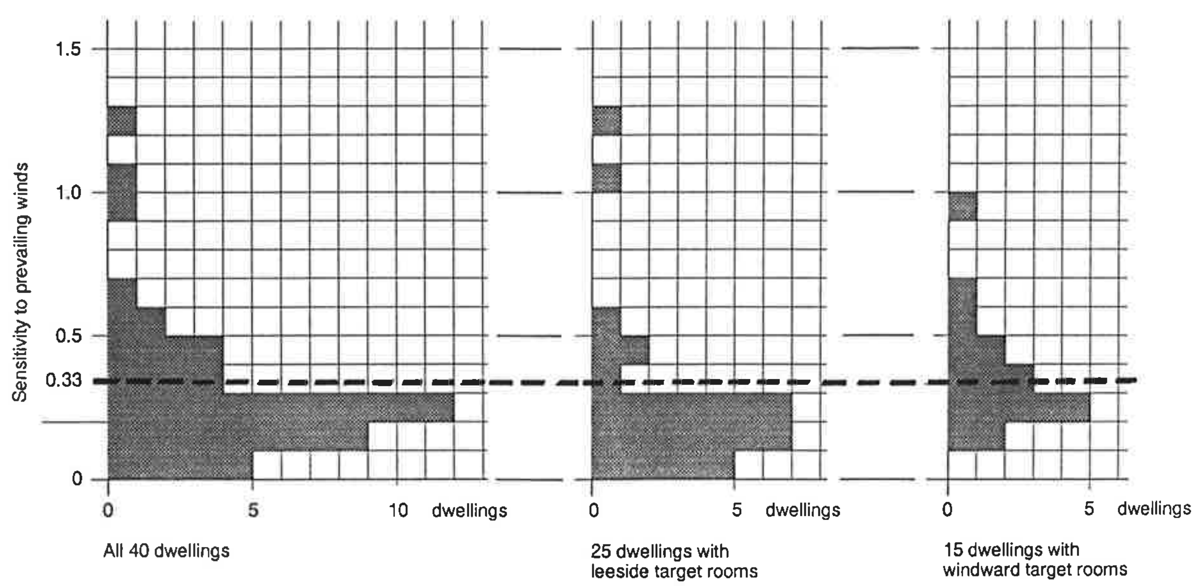

Fig. 10. Sensitivity to prevailing winds.

tered, facing mid-leeward. Lower external wind speeds may have been relevant to adverse ventilation effects for both subgroups.

Sensitivity to Prevailing Winds. As shown in figure 10, 4 of the 40 dwellings had close to 0.33 for the proportion of west or southwest to other openings. Ten had a higher proportion of such openings, and 26 had less (65%). Of the 15 dwellings with windward target rooms, such a marked trend was not apparent (47%). Possession of relatively few west or southwest openings was most characteristic of the 25 dwellings with leeward target rooms (76%).

Discussion

Occupancy and Symptoms

Although health effects were typically reported in terms of an individual's hypersensitivity without much reference to specific buildings, this study has considered the contribution of the home environment to continued ill health. This view was supported by the fact that most of the target persons had lived in the same house for many years, and in 25 dwellings, at least one other occupant reported similar hypersensitivity, although usually less severe.

For the group of 40 target persons, volunteered symptoms showed a similarity in type and occurrence to symptoms of the sick building syndrome (SBS) described by Burge [12], who noted that subjective symptoms such as 'tiredness, lethargy and headache' were most common. The higher proportion of female target persons in the 40 dwellings, about 3:1, also agreed with previous observations for both work and home environments, of greater frequency of such symptoms among women [13]. However, no gender difference was apparent with the 11 affected children.

Occurrence of SBS in the home environment is less easily investigated than in the workplace. For instance, one definition of SBS for office buildings [14] requires that more than 20% of occupants report symptoms, but the numbers of occupants in houses is too low for such definitions to be useful. Even in a group of complaint dwellings, a frequency of over 20% for symptoms could be inappropriate for attributing ill health to the built environment, as family members may share an inherited predisposition to some illnesses.

Another characteristic used to distinguish SBS from other complaints is that symptoms recede within a few hours of leaving the building. In contrast to the occupants, this was generally so for the architects who visited the buildings during the course of a working day. However, the findings in the five worst situations, in which visitors suffered more than occupants, need explanation. One possibility is that the occupant was no longer surprised to experience symptoms and therefore did not show the same degree of alarm as the visitor. If some kind of physical adaptation had taken place in occupants, then the target person would be unwell all the time, while the unadapted visitor would suffer more acutely, but on a short-term basis only. This explanation was supported by considering the time spent in the dwelling each day, which was usually much longer than normal workplace attendance. Different health effects might result from exposure to the same indoor air pollutants over longer periods.

Some evidence has been observed [12] that symptoms associated with the workplace do not always resolve on leaving the building. In such cases, connection of symptoms with specific indoor environments would be less readily made, as in the present study. Therefore the emphasis was placed on testing for such a connection through identifying spatial characteristics of the buildings which could be linked with greater exposure to indoor pollutants for the target person. An advantage of this approach is that objective data can be used, in most cases verifiable for years after a visit even if the person has moved.

Spatial Characteristics of Dwellings

The buildings as a group initially appeared to have nothing in common which could cause negative health effects. The apparent frequency of basic building faults, such as dampness, may have been important, but was not sufficient to link the group as a whole with health effects. Nor could the presence of leeward bedrooms distinguish a problem building type, as dwellings with 3 or more bedrooms are very likely to have at least 1 to leeward.

In the group as a whole, there was little bias in orientations of major elements, such as walls, living rooms or bedrooms, other than as influenced by streets. However, 5 of 9 spatial factors tested showed characteristics that could indicate adverse ventilation, being related to target rooms, bathrooms, external doors, site slopes and openings mid-windward. As seen in figure 3, target room orientations represented an increasing proportion of all bedroom orientations, from a low at southwest to a high at east. The consistently stepped gradations between the eight values suggested an effect common to most dwellings.

Three irregular characteristics were apparent in the group as a whole. They were (1) bathroom window orientation, which overall was both windward and relatively sunless; (2) most sites sloped down to leeward, and (3) dwellings had relatively few mid-windward openings. This gave a broad indication of reduced external wind speeds and a potential moisture removal problem in the group. The observation was in line with previous findings [5], leading to the recommendation that no general air-tightening of the housing type for energy saving should be made, because some existing houses, even when occupied, were likely to have air change rates inadequate for moisture removal when wind speeds were below average.

For the subgroup of 25 dwellings with leeward target rooms, below-average ventilation rates due to a low proportion of mid-windward openings, but also to wind-sheltered sites, were indicated. The prevalence of southeast slopes could also have indicated a trend to slower-drying, shaded soil and surroundings.

For the other 15 dwellings, a lack of windward openings was not characteristic, suggesting that any adverse ventilation effect would be associated with an imbalance of airflow between windward rooms and passages, not necessarily under-ventilation. For the 7 dwellings with sheltered, windward target rooms, airflow patterns may have had more in common with the subgroup of 25 dwellings with leeward target rooms. In either case, whether by lack or imbalance of airflow, all target rooms may have often had less airflow than similar rooms in the same dwelling.

A Building-Related Health Effect

The main clue as to the nature of a building-related health effect common to most dwellings appeared from the spatial relationships between target rooms and bathrooms. In figure 8, it can be seen that the presence of at least 1 windward bathroom in a dwelling defined a subgroup of target rooms with an orientation pattern very similar to that of the 32 'leeward or sheltered' target rooms (fig. 2). It accounted for the easterly bias of the overall target room distribution, with the remainder of the cases showing little resemblance to this pattern. An associated negative health effect could be due to three different mechanisms:

(1) collection of all types of pollutants from the indoor environment on an airflow path from the outdoors through windward bathrooms, continuing along internal passages, with the most accumulation in the less well-ventilated rooms, particularly the target rooms;

(2) deposition of moisture in target rooms and subsequent localized mite or microbial growth in bedding or on room surfaces; or

(3) local generation of a pollutant within bathrooms, associated with microbial growth on surfaces or in the water supply, readily airborne or carried on aerosols for distances of at least 5–20 m at low air speeds.

Any or all of the three processes could have been occurring in most of the dwellings. However, if the general sunlessness of bathrooms allowed for a significant pattern of microbial growth, or for survival of significant airborne pollutants, the third alternative would be most likely. Thirty-six of the 40 dwellings had at least 1 bathroom oriented to the least-sunny sector. The airflow mechanisms noted could provide for the spread of soluble products from bacteria or fungi through the dwelling overnight, following evening showering. Bedroom orientations could be broad indicators of occupant exposures, according to the values for target rooms (fig. 3). If so, the health effect might be caused by regular exposure to a substance having the ability to induce continuing hypersensitivity symptoms.

Implications

This analysis of building form had implications for the particular housing type and region, for pollutant testing procedures as well as for identifying valid remedial measures. There were also implications for other areas and building types.

First, for what target substance would one test in such housing, and where? Naturally ventilated buildings may have high levels of microbiological contaminants that are not necessarily causing SBS type symptoms [12], such as spores from outdoors. The analysis of building form and occupancy patterns presented here could be used to predict least and most likely sampling sites and times, and also to identify likely good and bad buildings for testing. Provided the 'target substance' was included in those tested, it might be evident by comparing patterns of results for different places and times, rather than overall levels.

Second, this study showed that some of the remedial measures favoured in housing for hypersensitive individuals, such as the replacement of building materials and the provision of sunny bedrooms, could have been inappropriate – even ensuring that the health effect continued. There was some indication that the remedial measure of moving to a randomly chosen house could be more effective. Perhaps two of every three such moves might avoid the grouping of spatial factors characteristic of these complaint dwellings. The main implication of this study for remedial measures in other temperate regions was that healthiness of habitable room orientations may depend more on wind characteristics than sun. Moisture deposition according to building forms which affect air movement has been previously noted with stairwells in the UK [10] and plan layouts in the FRG [8]. Modes of ventilation might include buoyancy, and mechanical as well as wind-influenced, according to seasonal conditions and building type.

The idea that built form can affect human health and well-being has been often expressed in building lore. Such traditional guidelines usually applied to a limited geographic zone and sometimes were expressed in mystical terms, but often they dealt in principle with the interaction of built forms, airflow and moisture. An example is the Chinese concept of 'feng shui', translated as 'wind and water' [15]. This study has shown that built form may have links with health in relatively high-standard modern housing, probably by affecting airflow and moisture dispersal. The study raises the possibility that some types of problem buildings may be identifiable from their forms.

Acknowledgements

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