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Biological Consequences of Environmental Control through Housing

by Douglas H. K. Lee*

Housing was originally devised as a control of the thermal environment, but numerous other functions have been added with resulting competition and confusion. Current design gives insufficient attention to thermal factors and relies upon supplementary heating and cooling to compensate for faults. These are wasteful of energy, and the exhaust from air conditioners adds to the heat island conditions in city cores. The impact of consumerism on domestic space and the importance of personal space and privacy are reviewed.

From the time that man huddled in caves against the rigors of the last ice age, housing has been the universal mode of personal climate control. As the complexity of life increased and developing sophistication multiplied his needs, housing was called upon to meet an ever widening variety of demands. Today, housing is expected to provide complete protection against climatic vagaries, furnish space to occupants with quite diverse interests, conform to both personal and communal standards of construction, serve as a repository for personal possessions, provide security against depredations, give an identifiable place of abode, include convenience of access, allow easy maintenance—and all with maximum efficiency at minimum cost.

Attempts to achieve the impossible have resulted in some clearly visible trends, such as more substantial construction, smaller and more tightly built units, condensation into urban agglomerates, built-in temperature control, introduction of "gadgets" unlimited and consumer products without end, and a complex system of fiscal underwriting that threatens to choke on its own complexity. The best of intentions are being frustrated by unforeseen repercussions, contributions to health protection are in danger of subversion by household risks, repose and security are undermined by social and economic fears. In this situation it is wise to analyse and weigh needs and consequences against each other so that a considered balance can be struck and unnecessary threats to both environment and human aspirations can be avoided.

Housing as Environmental Protection

Landsberg, in his introductory remarks to the Session on Housing, listed the major atmospheric variables against which housing can be expected to afford protection. I wish in this presentation to take up the matter of protection against thermal factors in particular, and to illustrate the complex nature of the considerations involved, the way in which nonthermal requirements overlap, and the somewhat simplistic approach that

* 3204 Arrowwood Drive, Raleigh, North Carolina 27604.

has dominated architectural design in this country.

Heat exchange between the occupant, the surrounding house, and the external environment involves four physical factors: temperature, humidity, radiant heat, and air movement. The thermal function of housing is to reduce the fluctuations of external conditions to the point that, with the further aid of clothing, they are at least tolerable, and preferably acceptable to, the occupants. The more effective the control exercised by the house structure, the less will additional measures be necessary to keep internal conditions within desired limits. The trend to more substantial and more tightly constructed units is directed towards this end. Unfortunately, other features of design have not always gone in the same direction, and other functions often compete for consideration. For those who like to think in quantitative terms, the exchange of heat between the interior and the external environment can be summed up in the (simplified) equations (1)–(3).

$$\text{Heat loss by conduction-convection} = K_{cc}\left(\frac{t_i - t_e}{I_s + I_o}\right) \quad (1)$$

$$\text{Heat loss by evaporation-convection} = K_{ec}\left(\frac{p_i - p_e}{r_s + r_a}\right) \quad (2)$$

$$\text{Heat loss by radiation} = K_r\,(T_s^4 - T_o^4) \quad (3)$$

Here the K are constants depending on the units employed, t is temperature, p is vapor pressure, I is insulation, r is resistance to the passage of water vapor, T is absolute temperature; and in the subscripts i stands for interior, e for exterior, s for the structure, a for the air, and o for surrounding objects. Clearly, the flow of heat will vary with the structure from point to point and with the atmospheric conditions from time to time. The fluctuations will generally be greater in the external than in the internal conditions. From these equations the points at which heat flow can be controlled to best advantage can easily be predicted.

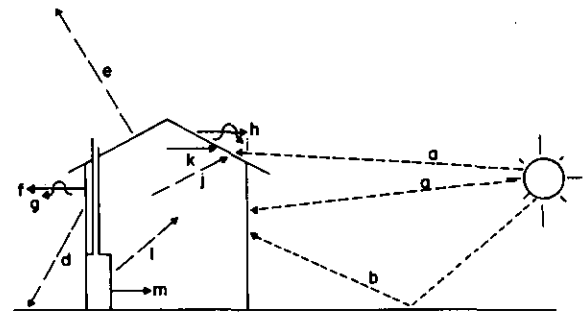

FIGURE 1. Major heat exchanges between house and cold, dry environment: (*a*) direct solar radiation, weak; (*b*) solar radiation reflected from ground, weak; (*d*) thermal radiation to ground, medium; (*e*) thermal radiation to sky, medium to strong; (*f*) conduction to cold air, strong; (*g*) air movement accelerating transfer, medium to strong; (*h*) conduction from roof to air, strong; (*i*) air movement accelerating transfer, medium to strong; (*j*) thermal radiation to cold roof, medium; (*k*) conduction to cold roof, strong; (*l*) thermal radiation from heating devices, variable; (*m*) conduction from heating devices, variable. Reproduced with permission of North Holland Publishing Co., from Lee (*9*).

The directions of heat flow by various physical channels under typical cold dry and hot dry conditions are illustrated in Figures 1 and 2. It will be clear that insulation against heat transfer, from inside out in the cold, and from solar heating inwards under hot conditions, is a most important feature of house design. Inasmuch as the entry of wind into a structure reduces its insulative value and increased air movement inside the dwelling increases heat loss from the occupants, a second most important aspect of design for cold conditions is exclusion of wind. Under hot conditions, insulation is needed in the roof structure and in those walls which are subjected to solar heating. The type of insulation needed under cold conditions, where the gradient is always from within outwards, differs from that required under hot conditions against a diurnally varying solar heat load. In the former case, the physical property that is important is a low thermal conductivity, but where there is a fluctuating load the thermal diffusivity, which involves the thermal capacity as well as the conductivity, is important. The difficulty about a cyclical load is that resist-

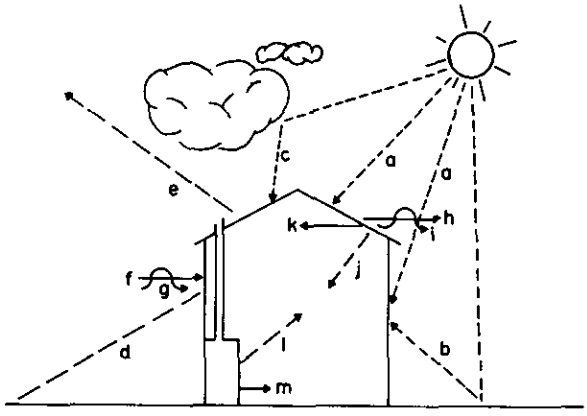

FIGURE 2. Major heat exchanges between house and hot, dry environment: (*a*) direct solar radiation, strong; (*b*) solar radiation reflected from ground, medium; (*c*) solar radiation reflected from clouds, weak; (*d*) thermal radiation from ground, weak; (*e*) thermal radiation to sky, weak to medium; (*f*) conduction from hot air, weak to medium; (*g*) air movement accelerating transfer, variable; (*h*) conduction from hot roof to air, medium; (*i*) air movement accelerating transfer, variable; (*j*) thermal radiation from hot roof, medium; (*k*) conduction from hot roof, medium; (*l*) thermal radiation from heating devices, variable; (*m*) conduction from heating devices, variable. Reproduced with permission of North Holland Publishing Co., from Lee (*9*).

ance offered to the inward passage of heat when the sun is up also interferes with the outward passage of heat when it is down. The density of material gives a rough guide to its thermal diffusivity as well as its conductivity. Vegetable materials of fairly low density are good for both types of insulation. Dense materials interfere less with insulation against cyclical heat loads than against continuous gradients (*1*). The effect of insulation against cyclical heat loads is to reduce the amplitude of the temperature fluctuation on the inner surface and to postpone the time at which maxima (and minima) occur. It does not, however, change the mean temperature, which will be the same on both surfaces. The greater the air movement over the outer surface at the time of heating, the less the amount of heat that enters the structure. It is quite important, therefore, that the roof be designed to permit wind flow over its surface in hot climates, but protected from wind in cold climates where the solar heating is welcome. Yet we seldom see consideration given to this feature.

It would be very nice if there were some natural way of reducing the vapor pressure in warm humid climates. Unfortunately, the only "natural" way of reducing temperature, by evaporation of water, works well only in hot dry climates, and simply increases the humidity in humid climates.

An important item not brought out in eq. (1)–(3) is the effect of the total surface area of the house, and its orientation to the sun. For a given cubic capacity, the surface area through which heat transfer takes place is least for a cube. Slab-sided structures and rambling layouts greatly increase the surface area as well as increasing the cost of construction. Minimization of surface area is important in cold climates where the structure has continually to retard heat loss. Orientation to the sun is important in middle latitudes, particularly if the horizontal cross section departs from the square. At latitude 40°, for example, a slab-sided structure (such as the United Nations building in New York) whose long axis runs N-S intercepts much more solar radiation in summer than the same structure oriented E-W. In winter the difference is much less, so that the saving of fuel in winter does not compensate for the energy used in air conditioning in summer. In low latitudes, the relationship of the sum to the structure varies so much during the year that the only areal consideration of importance is that of the roof, and in many instances the solar heating of the roof can be minimized by permitting winds to flow readily over its surface, as explained above.

Supplemental Control of Thermal Conditions

To the extent that the internal conditions are not controlled by the structural features to the satisfaction of the occupants, energy-dependent devices must be called upon to rectify the deficiencies. Various types of equipment, with varying degrees of efficiency, can be used for space heating or radiant heating of the occupants. The most

venerated of these devices, the conventional fireplace, tends perpetuate a longstanding error in drawing input air across the room and its occupants instead of through conduits from outside. In warm humid climates, the simplest way of improving internal conditions is by relatively slow speed overhead fans. Once the only available device in the tropics, these effective fans were displaced by high speed wall fans or by various and mostly inefficient hassock fans. It is pleasing to see them coming back into popularity. Air conditioning primarily lowers air temperature, but if this is reduced to the prevailing dew point temperature, as usually happens in warm humid weather, then moisture is removed as well. But both heating and air conditioning are wasteful of energy. For a long time architectural engineering in this country relied upon the use of these energy-consuming devices to make up for neglect of insulation, compact design, and orientation. A bigger heater or air conditioner was the easy answer to structural deficiencies. This no longer makes sense even in this country; it never did in the economies of less affluent (and less wasteful) countries. It is a bit late to change the design of existing structures, but it is to be hoped that the lesson will be applied in future housing design.

Temperatures below the comfort zone for a particular person—and the limits vary with climatic location, past experience, age, and many other factors—produce dissatisfaction and lower productivity, whatever they might do by way of favoring reproductivity. Heating devices, on the other hand, bring their own difficulties and hazards. Fire is an ever-present risk, particularly with those devices that use liquid fuel or require personal manipulation. Failure of electric wiring is attended with more risks where heavy amperage is used, particularly when heaters are added without consideration for the capacity of existing wiring, as can readily happen in times of energy shortage.

The low relative humidity produced when winter air with low vapor pressure is heated produces annoying dryness of the nasal passages in some people. Whether it goes further and encourages respiratory infection is a matter on which opinions vary. The dryness can be somewhat alleviated by evaporating water (and using more energy), but only if the walls have been made fairly impermeable to water vapor. Walls not so treated let water vapor out as fast as it is generated, except temporarily in the bathroom or kitchen. One would think that by now everybody would know about the risk of carbon monoxide when charcoal is burned in confined spaces, or when stoves with smoky flame are not ventilated to the exterior, but every winter some individuals lose their lives from malfunctioning stoves. The more compact and tighter the house construction, the greater this risk (and also potential risk from other toxic materials, such as some insecticides, liberated indoors).

Deconditioning for prevailing external conditions is very likely to occur in those who sequester themselves in regulated interior environments. Some of this deconditioning is psychological, an unwillingness to face less than comfortable conditions. There are physiological aspects also. The incidence of cardiovascular catastrophes shows a seasonal increase in areas with harsh winter conditions. One explanation is that, as one moves rapidly from warm interiors, where skin blood vessels are dilated, to cold exteriors, the constriction of those blood vessels produces a rapid, although temporary, rise in blood pressure, and this may be sufficient to provoke a catastrophe where the stage is already set by disease. In a healthy peson the rise may be regarded as a useful "training" exercise, but the hope sometimes exceeds the fact.

Until recently, a sudden failure of power supply was regarded as a rare event, but the winter of 1973–1974 brought to many in the northern part of this continent the alarming prospect that at least partial failure may become a commonplace. That there were no epidemics of respiratory disease last winter strengthens the belief that such infections

are associated more closely with the variable weather of spring and fall than with the continued stress of winter. The coming winter may confirm or deny the validity of this belief. It seems only reasonable to suppose that persons subjected to continued cold stress would suffer some loss of resistance to other stresses, such as infection, particularly if energy shortage also interfered with their nutrition. We have become so dependent upon supplementary heating that the consequences of a marked shortage of energy upon the health of elderly persons, now constituting an important proportion of the population, is a matter of concern.

While there are many areas that cannot be occupied in winter without some form of heating, there are very few locations where the conditions cannot be at least tolerated in summer. Air conditioning was virtually nonexistent fifty years ago; today it is a social necessity in large parts of the country, even in the northern states. That people like it, are more comfortable, and more willing to live in hot areas is clear enough, and there is a certain amount of evidence that at least mental work is more productive in air-conditioned quarters, but air conditioning is not essential for life in the way that heating is indispensable in the cold, and in many situations attention to house design and construction, utilization of natural breezes, and employment of shade can make air conditioning unnecessary, even in the tropics. However, air conditioning is here to stay. It can be used with greater circumspection and less risk of deacclimatization of the occupant than is presently done. As with heating, the principal risk comes from sudden transitions or deprivation. A person accustomed to air conditioning will quickly experience some degree of heat exhaustion, ranging from headache and nausea to fainting, if suddenly deprived on a hot day, whereas one not so sheltered will wonder what the fuss is about. Heat stroke practically never occurs in acclimatized persons engaged in work for which they are trained. The 125 cases of fatal heat stroke reported for the U.S. armed forces in World War II (*2*) all occurred in the United States.

There is another, seldom realized, hazard that results from the use of air conditioning, and that is to those who do not have it. Air-conditioning equipment is a hungry consumer of energy. A modest window unit, for example, draws 1 kW, or more than 16 60-W light bulbs. All of this is passed to the exterior as heat, plus whatever heat is removed from the interior. This represents six times as much heat as a person doing light work and constitutes an undesirable load on the environment of an urban core that is already several degrees warmer than the surrounding suburbs (see later). Large units serving houses or apartment buildings add correspondingly more heat. Redistribution of heat is fine in principle, but is unfortunate in practice for those who have to be where the heat is moved to.

Urban Heat Islands

The agglomeration of buildings in central portions of cities results in higher temperatures than in peripheral suburbs, as has been amply demonstrated by Landsberg for Washington, D.C. (*3,4*). Clarke has shown this also for New York City on the occasion of an epidemic of heat deaths in July 1966, and for St. Louis, Missouri, in June, 1953 (*5*). The following quotation from Henschel et al. (*6*) concerning the July 1966 epidemic of heat deaths in St. Louis illustrates the consequences:

> "It is obvious that the heat deaths were not randomly distributed throughout the area but were clustered within the city-core area. Many factors might account for the fewer deaths occurring in the suburbs. The population density is lower in a suburban residential area. The more open areas with grass, trees, and so on, in the suburbs would tend to reduce the air temperature and accelerate radiative heat loss, particularly at night."

Figures 3 and 4 from a paper by Buechley et al. (*7*) compare the maximum temperatures of counties or boroughs in the New

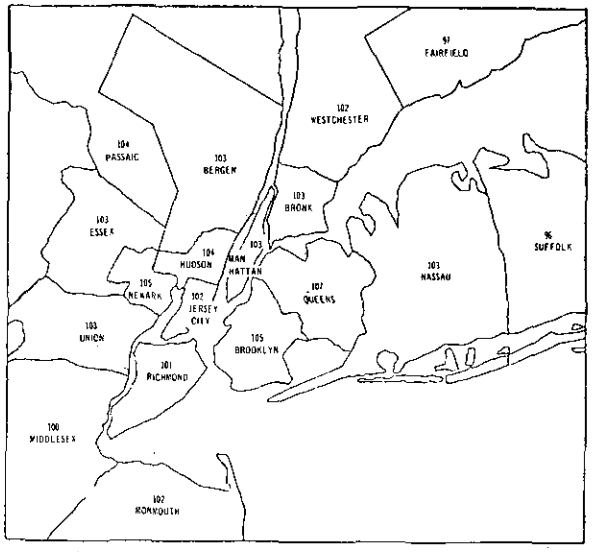

FIGURE 3. Maximum temperatures, New York—New Jersey area, July 3, 1966. Reproduced with permission of Academic Press, from Buechley et al. (*7*).

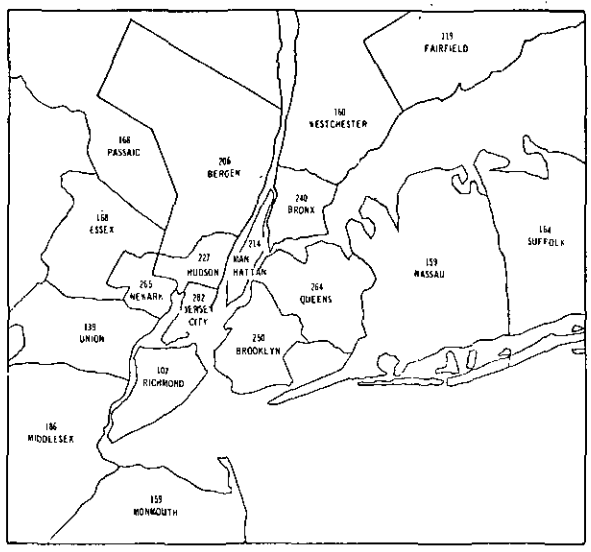

FIGURE 4. Mortality ratios, New York—New Jersey areas, July 4, 1966. Reproduced with permission of Academic Press, from Buechley et al. (*7*).

York–New Jersey area on July 3, 1966, with the mortality ratios (observed deaths/expected deaths) on the following day. It is quite clear, not only that urbanization results in higher city temperatures, but that the difference can produce a much higher proportion of deaths during a heat wave.

The factors producing "heat islands" are probably numerous. One major factor undoubtedly is reduction of average windspeed (*8*), so that solar heating is not dissipated so readily. Commercial and manufacturing activity undoubtedly adds its quota. Another contributor is probably the retention of heat by the exposed surfaces of city buildings, pavements, etc., which radiate mainly to each other at night instead of to the sky. It is this accumulation of heat in a heat wave, coupled with slow physiological adjustment to an overload, which combine to produce a sudden epidemic of deaths after some three days of continued excessively high temperatures. To these "natural" thermal effects must be added the fact that a large proportion of those who live in core areas, as contrasted with those who merely commute to work, are relatively poor and occupy the least protective housing—the top floor of a tenement could substitute for purgatory in hot weather. Affluent apartment and penthouse dwellers who elect to live in core areas have the advantage of air conditioning, but at the further expense of those who do not have such provisions and can merely suffer.

Impact of Consumerism

Up to the time of World War I, the cherished possessions of the majority of people did not extend much beyond the piano, the sewing machine, and the knick-knacks on the what-not. With the rapid growth of technology and the spread of relative affluence, demands have multiplied, encouraged by continuous pressure to "keep up with the Joneses". Industry has not been backward in appeasing the appetite that it has helped to create. The resulting plethora of "gadgets" and "gismos" (it is hard to find other expressive terms for our acquisitions) would bewilder and perhaps shock our Victorian ancestors.

The writer's is quite a modest household

in this respect; we have no electric toothbrushes or letter openers. But a casual inventory revealed the following power consumers: stove with two ovens, blender (which is also an excellent ozone generator), ice crusher, iron, electric carver, electric can-opener, refrigerator, dishwasher, garbage disposal, hot plate, toaster, electric grill, waffle iron, electric coffee pot, vacuum cleaner, hi-fi radio and record player, two typewriters, mixer, another radio, air conditioning and heating system, ventilation fans, power drill and saw, electric garage doors, and, of course, two cars! Parents of teenage children could easily extend this list. The presence of this array increases the demand for space, raises the noise level (even in the absence of teenagers), generates heat, and imposes a constant need for repairs and replacements. Though restricted by current fiscal uncertainties, the average householder's list can be expected to grow as inventive ingenuity continues its pressure.

The above items pose little risk apart from power tools, but the same cannot be said for the galaxy of chemicals that most households acquire. In the cupboard below the sink the writer found: bathroom cleaner, 409, Twinkle, Comet cleaner, Fantastik spray cleaner, dishwasher detergent, Jet dry, Brasso, sevin, silver cream, Easy-Off, Janitor-in-a-Drum, oven cleaner, pest killers, roach and ant killer, liquid plant food, flea and tick spray—a list as remarkable for the catchy names as for its varied composition. (The use of proprietary names does not signify endorsement!) Many of these materials are harmless, but some are not. Caustics and some pesticides could present some danger to children or other careless persons. The medicine cabinet was virtually bare, but many can be seen that are veritable mini-pharmacies, posing risks for children and even for naive adults. The experience of the nation's poison control centers bears ample witness to the reality of these dangers. Protected space is required for these hazardous materials.

An inevitable consequence of growing consumerism is the generation of increasing amounts of domestic waste. It has been estimated that over 10 lb/head of household, commercial and industrial solid waste is being generated daily in the United States, or about 360 million tons/yr. The fraction to be attributed to domestic waste varies, but even at an average of 20% of the total the volume is stupendous. Containers—bags, cans, bottles, boxes, wrappings—account for a large fraction of the daily trash, as do newspapers, magazines, and other discarded print. (The poet Martial is said to have sent a sponge along with his poems so that the inscription could erased and the parchment recycled; perhaps we could learn something from this.) Accommodation has to be found in the house for the daily contribution and some exterior receptacle for that awaiting collection. Poorly constructed or badly maintained receptacles contribute to soil pollution and vermin breeding. An annual increase of 5% in per capita consumption, coupled with a rise in population, is rapidly compounding this problem.

Personal Space and Privacy

As pointed out elsewhere (*9*), organization of space is a prime concern of architectural design. To the original objective of providing space for material needs, must now be added consideration for the psychological effects that space and its treatment may have upon the occupant. Logical analysis and evaluation of these effects, however, present many difficulties. Among the various reasons given for emphasis on the treatment of space one may note in particular: control of interpersonal relationships, with provision for both social contact and personal privacy; scope for personal activity, whether productive, routine, or recreational; a personal sense of freedom, or at least of nonconfinement; a very real although indefinable sense of esthetic satisfaction.

The nature and extent of these requirements vary greatly from one person to another, and two individuals will seldom define

the ideal in the same way. But the compactness and very solidity of modern housing militate against many of these desiderata. When we add to this the noise level that seems inseparable from many younger people, the multiplicity of activities that vie for space, the number of household "conveniences" without which life now seems incomplete; and when we think of the rising cost of construction and the difficulty of financing that looms over us all, we can readily appreciate that space is likely to come out a poor loser and we with it. Expansiveness in the accountrements of living we have bought; ability to provide requisite space we have neglected. In a permissive and demonstrative age, the loss of personal privacy and retreat can only weigh heavily on the psyche. The few who can afford custom building may escape, but the vast majority who must perforce accept standardized and fiscally feasible housing face still another source of mental stress. It remains to be seen if man's resiliency can absorb all of this, and what effect the total stress may have upon his health and family harmony; but the outlook is not good.

Objectives and Repercussions

The substance of the foregoing analysis may be summarized in Table 1 comparing the worthy objectives of housing with the threats and failures that frequently ensue in the attempt to meet all requirements.

A bill of particulars such as this should, in all conscience, be followed by specific suggestions for improvement. In the matter of reducing energy consumption, significant savings could be made by greater attention to house design and construction. For cold weather, the adoption of cubical design, combined with good insulation and closure of inadvertent wind entries, is certainly to be advocated. For hot weather, roof insulation and ventilation of any roof space are important. In midlatitudes, orientation to minimize the solar load, judicious use of natural winds to cool heated surfaces and to provide interior air movement, and shading of surfaces exposed to the sun are very effective. The use of air conditioning should be restricted to that which is essential, and deconditioning of the occupants avoided as far as possible. Separation of buildings, avoidance of obstruction to wind flow, and minimization of paved surfaces may make all the difference between escape and disaster during heat waves in core areas.

Table 1.

Objectives	Threats and failures
Protection against climatic stress	High dependence upon the supply of energy
Security for the occupant and his possessions	Creation of heat islands in city cores
Protection of personal space and privacy	Development of urban agglomeration and social unrest
Provision of a family center	Interpersonal competition for available interior space
Space for activities of all occupants	Danger from household chemicals and medicaments
Meeting community status standards	High volume of waste requiring storage and collection
Satisfaction of esthetic aspirations	Climatic deconditioning of occupants
	Increasing economic constraints

Potentially dangerous chemicals and medicaments should certainly be kept in secure places away from inquisitive hands. (Rumor has it that parents turn to children for help in opening "child-proof" bottle tops.) The real safeguard, of course, is not to have dangerous materials around; but that is perhaps a pious hope.

The matter of space allocation and protection of privacy in a dwelling of restricted size is indeed troublesome. Moveable interior walls would permit adjustment of standard housing to individual needs. The incorporation of sound insulation in walls would reduce the decibel assaults from the noise-loving members of the family; some old-fashioned

discipline may also help. It seems that each family needs to work out its own least stressful regimen. As for economic difficulties, if a score or more of economists found themselves unable to direct the President in controlling "stagflation", it ill behooves this writer to venture opinions.

In summary, therefore, there is no overall solution to the shortcomings of current housing design. The "cookie-cutter" approach is unlikely to achieve a resolution. Developers, architects, engineers, and the public between them could effect improvement if they would think through the implications and consequences of their multiple demands, list priorities and costs, and work out what combination would give the best return to the particular user under his particular set of fiscal, social and psychological circumstances. Some guidelines have been suggested.

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