444 PASSIVE HOUSE IN TRADITIONAL WAY?

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ABSTRACT: The benchmark of the passive houses is a conventional specific value of the yearly heating energy demand per floor area.
Minimisation of transmission losses of walls and roofs is the question of adequate thermal insulation. The case of transparent elements is less simple: contemporary glazing systems of low U-values are less transparent than the normal one. The less the transmission heat losses, the more important are the ventilation losses. Radical decrease of ventilation losses is possible by mechanical ventilation with heat recovery, typical in existing passive houses.
Nevertheless, the mechanical ventilation in detached houses is not typical and besides of the aversion of the habitants (concerns relating IAQ, noise, exchange or cleaning of filters) there are some technical aspects to be pondered, such as the energy consumption of fans, the prevention of freezing. The question is whether the passive house standard can be approached *without* mechanical ventilation. Heating energy demand with and without mechanical ventilation and heat recovery, as well as with solar preheating has been calculated to evaluate whether the passive house standard may be approached in more traditional way.

Conference Topic: 2 Design strategies and tools
Keywords: passive house, operational energy

Introduction

Well-known problem of environmental pollution and limited fossil energy sources, on one hand, and the energy consumption, on the other hand, resulted in stricter building regulations and wide spreading of new concepts, such as low energy building, Dreiliterhaus, Ultrahaus, passive house.
The buildings belonging to one of these categories must meet a requirement: typically a threshold value of the specific heating energy demand per floor area and season must not be exceeded. The threshold value is a conventional figure: in the case of passive houses it is 15 kWh/m^{2}a. Although it would seem to be reasonable, no distinction is made with regard to the climatic zone or gross heating degree-hours.
To provide such a low heating energy demand the followings are necessary

- minimisation of transmission and ventilation heat losses;
- increased utilisation of solar and internal gains.

Minimisation of transmission losses of walls and roofs represents neither theoretical, nor practical problem – it is the question of adequate thermal insulation. With regard to the high insulation standard the thermal bridge losses can be minimised. The case of transparent elements is less simple: contemporary glazing systems of low U-values are less transparent than the normal one.
The less the transmission heat losses, the more important are the ventilation losses. Radical decrease of ventilation losses is possible applying air tight envelope and controlled mechanical ventilation with heat recovery, keeping the necessary minimum of the air change rate - typical in existing passive houses.
It is less difficult to achieve the passive house standard in a multi-storey building, e.g. in an office building, since (due to the absolute size) the surface to volume ratio may be lower, the internal gains are higher and in many cases the application of mechanical ventilation is typical.
Nevertheless, the mechanical ventilation in detached houses is not typical and besides of the aversion of the habitants (concerns relating indoor air quality, noise, exchange or cleaning of filters) there are some technical aspects to be pondered, such as the energy consumption of fans, the prevention of freezing.
The question is whether the passive house standard can be approached *without* mechanical ventilation. Self intended speaking of this standard not only the specific heating energy demand should be considered but the indoor air quality, as well. In other term, it should be supposed that the air change rate remains as low as that of the passive houses. Would be a better indoor air quality required and realised, it would result in the parallel shift of the heating energy demand in both of a passive house and a sample house.
It is another question whether the low operational energy consumption compensates the higher embodied energy, due to the quality and quantity of thermal insulation, high-tech windows, the planned change of the elements of the mechanical ventilation at the end of their effective life, the regular maintenance – the answer is not an unambiguous yes (Szalay. [1]).
In the recent paper only the operational energy need of small residential units of 80 -240 m^2 floor area (detached, semidetached and terrace houses) are encompassed.

Building Geometry

2.1. The surface to volume ratio

The analysed range of the floor area is between 80 – 240 m^2. Taking 2,8 m into account as typical ceiling height it corresponds 224 – 672 m^3 volume.

The surface to volume ratio (in other term the form factor) is of fundamental importance from the point of view of the ratio of heat losses by transmission and ventilation. At the same insulation level the more compact the form is, the lower will be the heat losses by transmission.

In general the surface to volume ratio cannot be substituted by other geometric data, such as perimeter to built-in area because in the last case the compactness in section is neglected. Nevertheless, strong correlation is possible if the ceiling height is given and uniform on each storey.

Following the typical layouts in form of parallelograms the quadratic one is the most compact, however, polygonal and curved, circular forms, moreover one and two storey versions are possible, too. The section may be of importance, as well: the Koppányi house (Budapest) with its hexagonal layout and domed heated attic quite well approximate a hemisphere (Fig. 1.).

In the given range of floor area the smallest unit can be imagined in one and two storey version with quadratic layout, its polygonal or circular version likely would not meet the everyday requirement with two storeis. Having one storey and quadratic form its surface to volume ratio is 1,16 m^2/m^3. Higher value is possible, if the layout is less compact. The same unit with two storey has a form factor of 0,99, whilst 0,85 would belong to a circular unit with one storey. (Regarding the small radius, two storey circular form is not taken into account, although such a building may be challenging for some designers.) Increasing the floor area the form factor decreases, beyond 200 m^2 floor area polygonal or circular layout can be applied in two storey version, too.

Besides of the total area of the envelope its distribution is to be considered, as well. Thermal insulation of attic floor slab, flat roofs or lowest floor slab is easier than that of the exposed wall.

The compactness of the building is limited by the depths of the plan, since the lighting and ventilation of the central part of a deep plan require either special solutions (e.g. toplits, sun ducts) or energy input. Another requirement is the provision of well insolated area of windows (and energy collecting elements, such as solar walls, collectors, if any).

If semidetached house is spoken of, one of the elevation is “adiabatic”, thus there is no heat flow to the neighbouring unit. The same applies to the end-units of terrace houses whilst the middle units have two “adiabatic” elevations. Self intended such an arrangement makes easier the decrease of the transmission losses, especially in the case of smaller two storey units.

2.2. The glazed ratio

The glazed ratio is the subject of a well balanced compromise since on one hand the U value of the window is higher than that of the opaque elements, on the other hand the solar gain represents an important contribution to the energy balance. At the same time the daylight aspects and the risk of summer overheating must not be forgotten. Self intended the orientation and the solar access are of fundamental importance (although the building site and the surrounding buildings may represent serious constrains). The problem of solar access is the same for passive and other houses

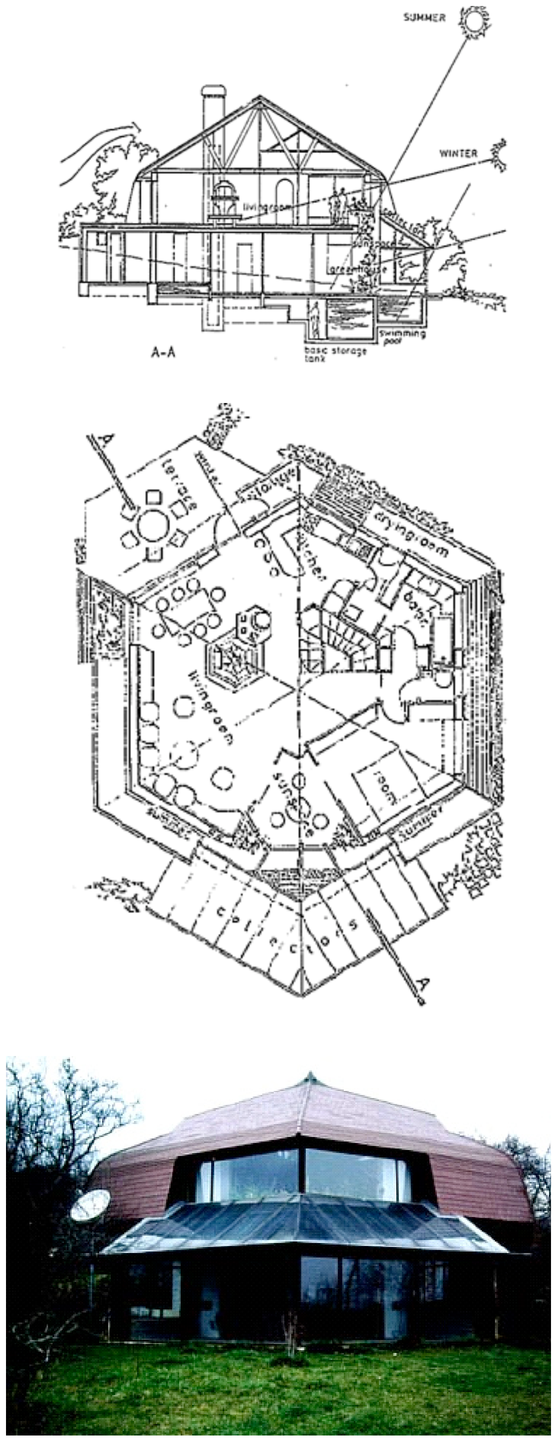

Fig. 1. The Koppányi house (Budapest, 1985) – an example of compact form, in both layout and section

The "standard" glazing of passive houses is triple, the nominal U value, including the frame is 0,8 Wm^2/K and the g value is 0,5. The typical window area is 10 – 20 % of the floor area. The glazing ratio certainly depends on the number of the storeys: the elevation area of two storey buildings represents a higher fraction of the envelope, thus the same window area results in lower glazing ratio of the elevation.
In order to prevent the summer overheating shading should be provided. If movable devices are used they can serve as night insulation. Although night insulation is more efficient in combination with poor quality windows, even good windows' thermal resistance can be improved by 10-20% - providing the movable night insulation is properly used.

2.3. Ventilation

The ventilation heat losses represent the crucial problem of passive houses. The transmission heat losses can be theoretically and practically decreased without limitation. The air change rate cannot be decreased below a minimal value, determined by the number and activity of the occupants. The standard solution of passive houses is a balanced mechanical ventilation system with heat recovery – this way 75-90% of the ventilation losses are covered by the heat flow from the exhaust air. The fresh air is filtered – this is frequently mentioned as a favourable fact. On the other hand the need of regular maintenance, cleaning or change the filters is a less popular, continuous task. An other concern is the deposit of bacteria, dust and fungi in the air duct - the cleaning cannot be easily solved. Further the problem of the noise is to be mentioned.
Self intended, one can argue with the high quality of ventilation and heat recovery units, with low noise level, with a well organised maintenance service – but even if it is not disputable, these concerns are in the background of the aversion of the habitants

3. Parametric study

The following parametric study is based on the following assumptions:
The gross heating degree-hour value is 72000 Kh.
The length of the nominal heating season is 4400 h. Both data comply with the statistical means of Hungary.
The length of the period when the heating system should be operated depends on the balance point temperature. The daily average indoor temperature in a free–running building can be approximated with the following equation:

$$\bar{t}_i = \bar{t}_e + \frac{A_F q_{cas} + \varepsilon A_{tr} g I_d}{\sum AU + \sum l\Psi + 0.35nV} \qquad (1)$$

where
t_i – the indoor temperature, ^{O}C
t_e – the external temperature, ^{O}C
A_F – the floor area, m^2
q_{cas} - casual (internal) gains, W/m^2

A_{tr} – the area of the transparent building elements, m^2
g – global transmittance of transparent elements,
I_d – average solar radiation intensity, W/m^2
A - the area of the exposed building elements, m^2
U – the heat transfer coefficient of the elements, W/m^2K
l – the length of the constructional joints, thermal bridges, m
Ψ- linear heat transfer coefficient, W/mK
V – heated volume, m^3
n – air change rate, 1/h
☐ – utilisation factor

Self intended the better the thermal insulation and the utilisation of the gains are, the shorter will be the period when the heating system should be operated, Nevertheless the operation of the mechanical ventilation in passive houses and the gains have to be taken into account for the nominal length of the heating season, thus for the periods, when the external temperature is between the balance point and the set indoor temperature.
The internal gain is supposed to be 5 W/m^2 (as it is in the German and Hungarian regulations).
The U value of windows is the "default" one, 0,8 W/m^2K, the g value of glazing is 0,5, both typical in passive houses. The solar gain is calculated with the transparent area of windows, whilst the transmission heat losses with the nominal size – 15% frame factor is considered. It is supposed that 50% of the glazing is Equator facing, 5% is opposite and 45% is East or West orientated, with undisturbed solar access. The irradiation for the heating season is 400, 100 and 200 kWh/m^2a, respectively (corresponding to the Hungarian statistical data). It means that a weighted average of 295 kWh/m^2a can be taken into account – this value may originate from other combinations of orientations, too. The estimated utilisation factor is 0,75. The glazing varies between 10 and 20% of the floor area.
The air change rate is 0,5 1/h. 0,45 Wh energy need is taken into account for every m^3 transported air.
The ceiling height is 2,8 m.
The floor area is between 80 and 240 m^2 for each unit. A single family house, a flat in a semidetached or in a terrace house can be considered as a unit. The surface to volume ratio range is from 0,6 to 1,3. The surface includes the exposed walls and windows, flat roofs, attic floor slabs or the envelope of a heated attic, the lowest floor slab, whatever is its position (over unheated basement, on the soil, arcade), partition walls to unheated spaces and "adiabatic" walls in contact with the neighbouring heated building.
One possible approach of the problem is to calculate the mean U value of the opaque elements necessary to comply with the passive house standard – having the results it can be pondered, whether the realisation is possible if the typical elements of passive houses are applied.
The calculation (of the necessary thermal insulation of the sample house, without mechanical ventilation) is based on the followings:
- for one square meter of the floor area the conventional heating energy need (the passive house threshold) is 15 kWh/m^2a ;
- to this conventional value the internal and solar gain is added, taking into account the utilisation factor;

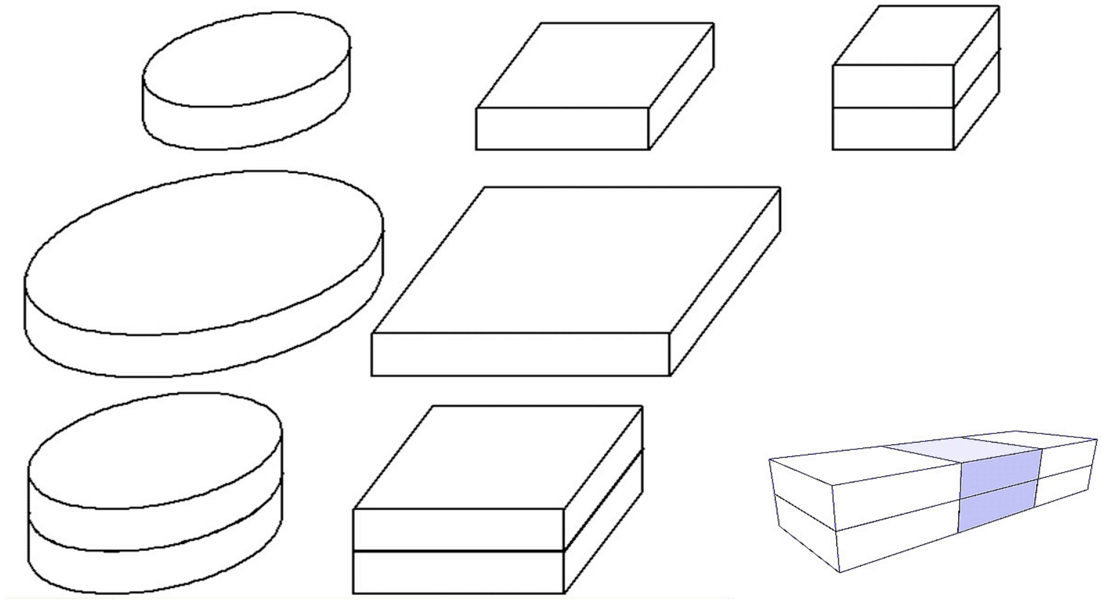

Fig. 2. The surface to volume ratio. First line: 80 sqm floor area, S/V 1,11, 1,16 and 0,99 Bottom left: 240 sqm floor area, S/V 0,94 and 0,97 for one floor, 0,68 and 0,72 for two floor options. The middle unit of the terrace house has two adiabatic walls.

- If no mechanical ventilation is applied, the energy consumption of the mechanical system - as an allowance - can be added, too, taking into account the primary energy "exchange rate" of electric power – the lack of mechanical ventilation facilitates to use this quantity of energy to cover the losses of the house.

Summarising these items we see, how much is the allowable energy need per floor area, which complies with the passive house standard. From this sum first the specific value of the ventilation losses should be deducted – the result is the specific transmission losses per floor area.

Having a given ceiling height the envelope area to floor area ratio is correlated with the surface to volume ratio, as well, as the window area to the envelope area ratio. The U value of the windows is pre-determined, thus the transmission losses due to the windows can be deducted from the total transmission losses – dividing the difference between the area of the opaque elements the mean U value of the last ones will be got. Hence, the "only" question is whether this U value can be realised.

The required mean U values of the opaque elements, necessary to fulfil the passive house standard without mechanical ventilation and heat recovery are shown in Fig. 3. As it was foreseen, the lack of heat recovery must be compensated with improved thermal insulation. Nevertheless, 0,12 W/m^{2}K is supposed to be acceptable as a mean value of the opaque elements. Self intended the compactness of the building is of fundamental importance: beyond a form factor the requirement can be fulfilled only if the unit has one or two adiabatic wall(s), thus in the case of semidetached or terrace house units.

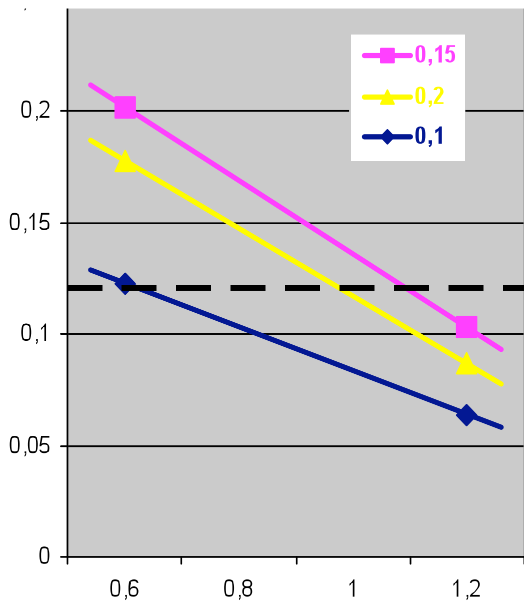

Fig. 3 The required mean U value of the opaque elements vs. the surface to volume ratio - the parameter is the window area to floor area ratio. Half of the window area is Equator facing. The dotted line marks the realisable threshold.

Very important is the role of the window ratio: it can be seen that it has an optimum. Less transparent area results in less solar gain, while transmission losses of high transparent area has to be compensated by the better thermal insulation of the remaining opaque elements. The parametric study shows that this optimum is between 0,10 and 0,20 of the window to floor area ratio. Self intended this statement applies only if the orientation of windows coincide with the given "mix": the less is the Equator facing window area, the lower glazing ratio will result in optimum.

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Solar preheating

The traditional solar measures include different techniques of preheating the fresh air. Sunspaces, conservatories, atria may improve the energy performance, but basically determine the architectural concept, therefore they will not be taken into account here.
The simplest preheating measure is a wall collector below the window with air inlet under the window sill (Fig. 4.).

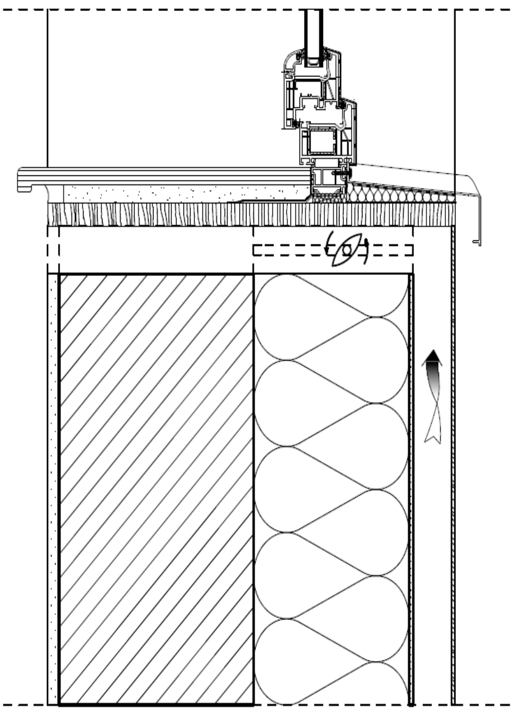

Fig. 4. A simple wall collector may cover a third of the ventilation heat losses during the heating season

The performance of such a wall collector can be estimated as follows:
The simplest preheating measure is a wall collector below the window with air inlet under the window sill (Fig. 4.). It is supposed that its height is 1 m, the 5 cm ventilated air gap is covered by single glazing, the U value of the wall does not exceed 0,2 W/m^{2}K, the absorber plate is a common one (α = 0,9).
A simplified estimation of the thermal balance can be expressed by two equations: one for the absorber surface and one for the air flow, as follows:

$$U_i(t_i - t_a) + Ig\alpha = h(t_a - t_m)$$
$$h(t_a - t_m) = 2 \cdot 0{,}35 \cdot L(t_m - t_e) + U_e(t_m - t_e)$$

where
U_i - the heat transfer coefficient of the wall between the room and the absorber, W/m^{2}K
U_e- the heat transfer coefficient of the glazing between the air gap and the external air, W/m^{2}K
I - the intensity of the solar radiation, W/m^2
g - the total transmittance (shading coefficient) of the glazing, -
α - the absorptance of the absorber plate, -
h - the surface conductance, W/m^{2}K
t_i- indoor temperature, ^{O}C
t_a -the absorber temperature, ^{O}C
t_m -the average temperature in the air gap, ^{O}C
t_e - external temperature, ^{O}C
L - air flow rate m^3/hm^2

If the climatic data of Hungary are taken into account, t_e = 3,6 ^{O}C and I = 91 W/m^2 as the average values for the traditional heating season, with this simplified calculation the following results are obtained:
At L = 15 m3/hm2 air flow rate the air temperature at the inlet is t = 9,6 ^{O}C thus the temperature increase is 6 K: it means that 36 % of the ventilation heat loss can be saved using the wall collectors. Self intended, the inlet temperature is lower on cloudy days and during the nights, but can be much higher in sunny days, covering not only the energy need of the ventilation, but even the heat losses by transmission.
Providing no ventilation is necessary, thus the inlet is closed and there is no airflow, at U_i = 0,15 W/m^{2}K, and at the average climatic condition the surface temperature of the absorber is the same as the set indoor temperature, thus no transmission heat loss occurs through the glazing covered wall area.
The necessary wall collector area is 6 – 20 m^2, it should be allocated below the windows on the Equator facing façade.
The key problem of the ventilation is the air flow control. Self intended, a passive house and a sample house without mechanical ventilation can be compared only, if the air change rate (and consequently the indoor air quality) are the same in both.
Having a mechanical ventilation system the air flow control does not represent a new problem. In the case of natural ventilation demand controlled tricky vents should be applied.
A promising new possibility is presented by L Jardinier et al. [2]. It is a humidity controlled air inlet. The relative humidity, as the indicator of the need of ventilation in living and bedrooms is a subject of discussion since it depends on the absolute humidity of the external air. This real problem has been solved by the authors. The sensor is sensitive to relative humidity in its "micro" environment. The local relative humidity depends on the absolute humidity and the temperature of the senior's environment which is linked to inside and outside temperature and so a controlled drift of the response curve (aperture vs internal relative humidity) is provided.

As far as the exhaust is concerned the control is simpler, eg. the passivent system can be applied. [3].

5. Conclusion

To prevent any misinterpretation the author does not argue against the passive houses with mechanical ventilation and heat recovery. Nevertheless, the aversions of the owners should be taken into account. Many of them do not wish to take care of a “machine”, to check and change regularly the filters, they consider questionable the indoor air quality and the noise. These concerns are completed with “technical” arguments: energy consumption of fans, physical life time. Last but not least the price of the system and the cost of operation and maintenance should not be forgotten.

Taking into consideration the above facts it has been analysed whether the passive house standard heating energy demand can be approached without mechanical ventilation and heat recovery. It has been stated that it is possible if the house complies with the majority of the following requirements:

The surface to volume ratio should be as low as possible – in smaller single family houses it requires compact form. Easier is the case of the semidetached houses and the middle units of terrace houses, due to the adiabatic walls between heated spaces.

Self intended the same high quality windows should be used than in the passive houses with a maximum U value of 0,8 W/m^2K and the overall U value of the opaque elements should be between 0,12 – 0,20 W/m^2K.

Solar gains have an important role, the glazed ratio has an optimum – if half of the window area is Equator facing, the optimum is about 15 % of the floor area. Certainly this ratio depends on the orientation and solar access and is to be checked case by case.

About a third of the ventilation heat loss may be saved if the fresh air is preheated in solar wall collectors.

The air change rate should not exceed that of the mechanical ventilation – it is of key importance to use demand controlled air inlet and exhaust. The appropriate ventilators are available on the market.

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