263: Zero energy renovation of Nemavo-Airey dwellings: a ventilation concept based on occupant behaviour

Laura Oerlemans, Michiel Ham

Eindhoven University of Technology, Eindhoven, The Netherlands
L.J.Oerlemans@student.tue.nl M.Ham@bwk.tue.nl

Abstract

In the Netherlands, the large demand for new housing after the Second World War was partly solved by using alternative building methods. The Nemavo-Airey system was one of these methods. Even though regarded modern and spacious at the time, these houses are now considered small, uncomfortable and energy inefficient.
In this research, an approach has been developed for the renovation of these Nemavo-Airey dwellings, resulting in more comfort for the occupants and a large extension of life span, while at the same time reducing the energy consumption for space heating to zero. A ventilation concept has been developed, based on the ventilation behaviour of occupants in the Netherlands.

Keywords: renovation, energy consumption, comfort, occupant behaviour, ventilation

1. Introduction

In the Netherlands there was a huge demand for new housing after the Second World War. Approximately a fourth of the pre-war housing stock of 2,2 million dwellings was either demolished or damaged during the war. [7] The construction of new dwellings and the repair of damaged ones were complicated by two factors: there was a shortage of building materials (e.g. bricks and wood), and also of qualified building construction workers (training institutes were closed during the war).
It was not possible to achieve a sufficiently high building volume by using only traditional building methods, since these traditional methods were all very labour intensive and a lot of bricks were required. Therefore, also alternative building methods were used, requiring other (better available) building materials and fewer, less qualified building construction workers. The Nemavo-Airey system was one of these alternative building methods.
Today, these Nemavo-Airey houses are considered outdated regarding space, indoor climate and energy performance and a great many of these houses have already been demolished. In this research, an approach has been developed for the renovation of these houses, resulting in more comfort for the occupants and a large life span extension, while at the same time reducing the energy consumption for space heating to zero.

2. The Nemavo-Airey building system

2.1 Introduction

The Nemavo-Airey building system originated from the Airey system, which was developed by Sir Edwin Airey in Leeds, United Kingdom, during World War II. The Dutch Government introduced the Airey system in the Netherlands in 1947, in order to give an impulse to the industrialization of house-building. [9] The original Airey system was adapted for application in the Netherlands by NEMAVO (Nederlandse Maatschappij voor Volkshuisvesting, Dutch company for housing). The adapted system was called the Nemavo-Airey (N.A.) system (see figure 1).

Fig 1. Nemavo-Airey houses in Enschede, the Netherlands [1]

2.2 System description

Walls in the Nemavo-Airey system consisted of small, prefabricated reinforced concrete columns, measuring only 62,5 mm x 125 mm (approx 2,5 x 5 inches) at a centre-to-centre distance of 625 mm (approx 2 feet). On the outside, reinforced concrete panels were placed against these columns. On the inside were woodwool cement slabs and a shiner course of pumice concrete blocks. Floors were usually made of steel lattice girders covered with wooden boards. Roofs were often, more traditionally, made of wooden beams covered with wooden boards and roll roofing or roofing tiles.

The largest part of a building could be constructed using materials that were better available, mainly concrete. Also, compared to traditional building methods, there was a large saving in the overall usage of materials and in the usage of qualified building construction workers. This way, the N.A.-system helped to bring the housing production up to the required standard.
More than 8000 single-family houses and flats were built in the Netherlands using this building system. [9]

3. The current situation of Nemavo-Airey houses

After the Second World War, Nemavo-Airey houses offered more comfort and space than existing, pre-war houses. They were often rented by relatively wealthy people. [7] The current situation is very different (in fact, quite the opposite): N.A.-houses are considered outdated regarding space, facilities, indoor climate and energy performance. A great many of these houses have already been demolished.
However, Nemavo-Airey housing developments also show some significant advantages today: the location close to facilities and the city centre is appreciated and the social infrastructure is generally very strong. Also, rents are relatively low.

4. Approach

This research focuses on the comprehensive renovation of Nemavo-Airey single-family dwellings. Its aim is to demonstrate that these houses can be drastically improved on comfort aspects as well as energy performance. This way, demolition becomes an unnecessary measure and the accompanied large-scale waste of materials and capital can be prevented. Also, the social infrastructure can be preserved.
Three themes have been approached in an integral manner.

4.1 Increasing comfort for the occupants

Nemavo-Airey houses do not meet today's standards regarding comfort. An important factor is that the dwellings are too small. A spatial design has been made by which the occupant's needs are met as best as possible (see section 6).

4.2 Improving flexibility and adaptability

Because of quickly changing occupant needs, flexibility and adaptability are becoming more and more important qualities of a house. Several measures have been proposed in order to increase flexibility and adaptability. One of these measures is the development of two different types of dwellings: a smaller and a larger type, with the possibility to convert the smaller type to the larger type at a later time with minimal effort (see section 7).

4.3 Reducing the energy consumption for space heating

In Nemavo-Airey houses a lot of energy is needed for space heating because of the poor thermal insulation and the existence of thermal bridges (note: this situation also has a negative effect on thermal comfort for the occupants). The consequences are a relatively large emission of carbon dioxide and use of fossil energy sources, and, because of rising energy prices, steadily increasing monthly costs for the occupants. Several measures have been proposed in order to reduce the energy consumption for space heating to zero (see section 8).

The expected result of this approach is that the life of the houses can be extended with at least 40 years, during which the renovated houses will offer sufficient comfort to the occupants, and have a minimal impact on the environment.

5. Case study: Nemavo-Airey houses in Helmond

5.1 Introduction

In the city of Helmond in the Netherlands (near Eindhoven) there is a neighbourhood with about 120 Nemavo-Airey dwellings, mainly single-family houses, owned by housing association 'Volksbelang' (see figure 2). The renovation approach is applied to these single-family houses.

Fig 2. Nemavo-Airey single-family dwellings in Helmond, the Netherlands

5.2 Size and layout

The houses in Helmond are very small: the usable area is 73,4 square metres (approx 790 square feet), divided over a ground floor and a first floor (see figure 3). For comparison: single-family dwellings built in the Netherlands after the year 2000 offer an average usable floor area of 168 square metres (approx 1800 square feet). [8]
The need for more space is demonstrated throughout the neighbourhood: quite a lot of houses have been enlarged by the occupants, mainly using do it yourself methods (e.g. using plywood and corrugated sheeting).

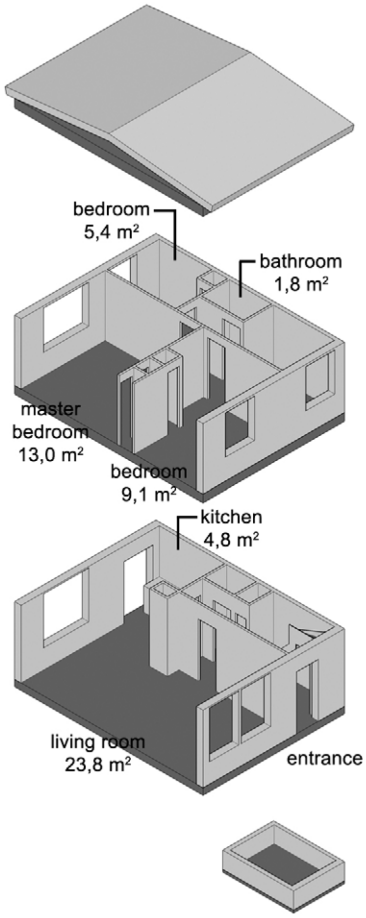

Fig 3. Layout of the N.A.-dwellings in Helmond

5.3 Occupant behaviour
Occupant behaviour is of great influence to the energy consumption of a building. In order to gain insight into the way the houses are used by the occupants, a survey has been carried out. It appears that, in general, only the space heating system on the ground floor is used. Sometimes the bathroom on the first floor is also heated. Bedrooms are almost never heated. The windows on the first floor are generally opened for large part of the day, even during cold periods.

5.4 Energy consumption
An average house (with average natural gas consumption, pattern of heating and pattern of ventilation) has been modeled using the Matlab Hambase program (developed at Eindhoven University of Technology). In order to verify this model, measurements of temperature, relative humidity and carbon dioxide concentration (in order to determine the ventilation rate) have been carried out. The outcome of the model has also been compared to the actual known natural gas usage in a specific year.
According to the model, 1.003 cubic metres (approx 35.400 cubic feet) of natural gas are needed for space heating in this average house. This means an energy usage of 133,4 kWh per square metre per year. Considering the poor (almost nonexistent) thermal insulation in the Nemavo-Airey houses, this exceeds expectations. However, it should be noted that only half of the house is actually heated, while the energy usage is divided over the entire floor area. When it is calculated based on the heated area only, the energy use for space heating is 266,8 kWh/m^{2}a.

6. Increasing comfort for the occupants

6.1 Introduction
A literature study has been carried out in order to gain insight into the meaning of comfort and in order to define several important aspects of comfort. [3,4,5] The measurements and layout of rooms appear to be very important. Also thermal insulation, sound insulation, flexibility and adaptability, and daylight and outlook appear to be very important in the overall appreciation of a house by the occupants. These aspects have been kept in mind throughout the design process.

6.2 Spatial design
Based on a comparison between several literature sources [2,3,6] a schedule of requirements regarding the spatial design has been formulated.
Improvement and enlargement of the kitchen, bathroom and second bedroom appeared to be very important, since these rooms were much too small in the original situation. Another important improvement was the addition of a washing and drying room (in the original situation the only suitable place for a washing machine was the kitchen). Also, the enlargement of the circulation space was an important item.
Based on this schedule of requirements, two different types of dwellings have been designed: a smaller type with two bedrooms, and a larger type with three bedrooms. In order to gain the extra space that is required, an addition is placed at the back of the dwellings, with an internal dimension of 5,2 by 3,3 meters (approx 17 by 11 feet). For the smaller type with two bedrooms, this addition is only placed on the ground floor. For the larger type with three bedrooms, this addition is placed on the ground floor as well as the first floor (see figures 4 and 5).
The result is a significant improvement and enlargement of the dwellings. The usable area of the smaller type of dwelling is 88,7 square meters (+ 20%, approx 950 square feet). The usable area of the larger type of dwelling is 106,6 square meters (+ 45%, approx 1150 square feet).

7. Improving flexibility and adaptability

Many of the Nemavo-Airey houses in Helmond only have one or two occupants. If these houses were to be renovated, it's expected that most occupants would choose the smaller type of dwelling.
It is possible that occupants will have larger demands in the future, or that the houses will be inhabited by larger families. It's important that the houses are adaptable to this possible change in occupant requirements.

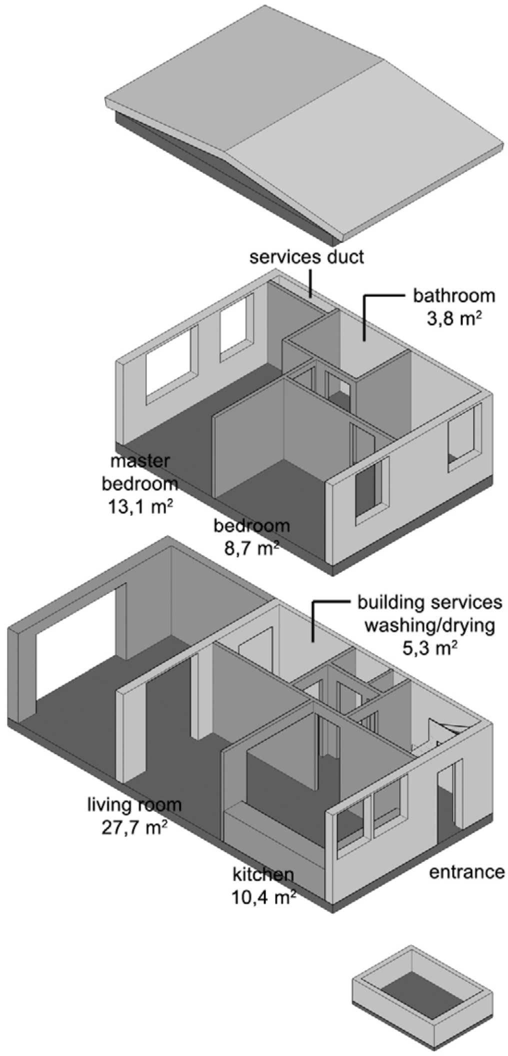

Fig 4. Improved layout, small type of dwelling
Walls and roofs to be added are shown in a darker grey

It's possible to convert the smaller type of dwelling into the larger type at a later time. The spatial design has been made in such a way that this conversion is possible with relatively little effort, cost and inconvenience to the occupants. The bathroom and the second bedroom remain intact, and the master bedroom is converted into two separate rooms.

8. Reducing the energy consumption for space heating

8.1 Thermal insulation measures

Firstly, the thermal insulation values of all building components have been raised in steps. It appeared that thermal insulation of floor, blank wall sections and windows is most effective. Thermal insulation of the roof appeared less effective (of course this was to be expected, since the first floor is not heated).

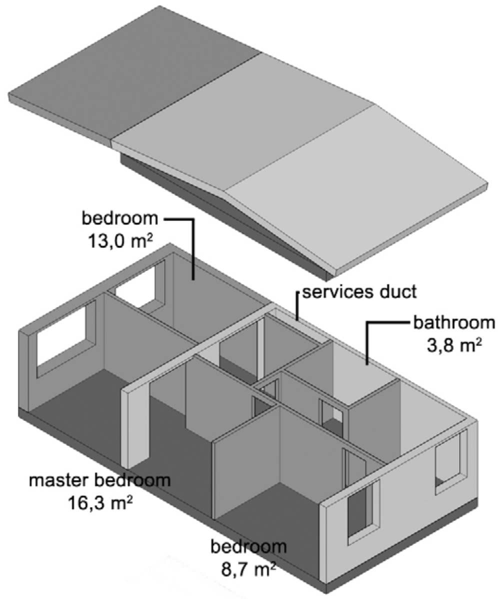

Fig 5. Improved layout, large type of dwelling
Walls and roofs to be added are shown in a darker grey

The following thermal insulation measures are proposed:

- Roof: thermal insulation value R=5 m^2K/W;
- Floor: thermal insulation value R=5 m^2K/W, except for floor parts that have to be insulated above the floor, which have a thermal insulation value R=2,3 m^2K/W;
- Upper floor: 30 mm of thermal insulation are added (R=0,75 m^2K/W);
- Blank wall sections: thermal insulation value R=5 m^2K/W, except for the basement walls, which have to be insulated on the inside and have a thermal insulation value R=2,1 m^2K/W;
- Windows: double (Argon filled) glazing with a U-value of 1,1 W/m^2K and a sun screen on the outside;
- External doors: thermal insulation value R=1,5 m^2K/W.

The high thermal insulation value for the roof seems in conflict with the fact that thermal insulation of the roof is less effective than thermal insulation of floors and walls. However, the basis of energy efficient housing is a very good thermal insulation. Some (not many) occupants of the Nemavo-Airey houses in Helmond do heat the first floor, and there might be more in the future. The high thermal insulation value for the roof means that also this deviating heating behaviour is possible in an energy efficient way.

8.2 Ventilation concept based on occupant behaviour

In low energy dwellings (for example passive houses), balanced ventilation systems with heat recovery are very common since using these systems can substantially reduce ventilation heat losses. For the correct functioning of these systems it is required that doors and windows are mainly kept closed during cold periods.

8.2.1 Occupant behaviour
In the Netherlands it's customary to ventilate dwellings by opening windows, especially in bedrooms (many people keep the bedroom window open during the night). This Dutch habit conflicts with the requirement for balanced ventilation mentioned before: keep windows closed.
The occupants of the Nemavo-Airey houses in Helmond also show this behaviour. The windows on the first floor are opened very often: on average more than 11 hours a day during cold periods (during warm periods even more often). On the ground floor, windows are opened less frequently, on average about one and a half hour a day during cold periods.
It is not to be expected that the occupants will radically change their ventilation behaviour when a balanced ventilation system is installed. Research in the Netherlands has shown that people generally do not adapt their behaviour when they move to a house with a balanced ventilation system. [10]

8.2.2 Consequences of occupant behaviour regarding the ventilation system
It can be concluded that a balanced ventilation system with heat recovery is suitable for the ground floor of the Nemavo-Airey houses in Helmond. This part of the dwellings is heated; therefore the effect of heat recovery is large. Doors and windows are not opened very frequently, so the ventilation system is not disturbed to a large extent.
However, on the first floor a balanced ventilation system does not seem a logical choice. The rooms are not heated; therefore the effect of heat recovery is smaller. Moreover, it's expected that the windows on the first floor will be opened very frequently, which would seriously disturb the balanced ventilation system, and which would of course also result in cold outside air directly entering the heated ground floor.
A determining factor is the comfort that a ventilation system offers to the occupants. Occupants of the Nemavo-Airey houses (and, in general, houses in the Netherlands) appreciate 'fresh' air in bedrooms (otherwise they wouldn't open the windows this much). Air supplied through ventilation grilles or open windows is cool and feels 'fresh'. Air supplied by a balanced ventilation system is not cool and does not feel 'fresh'. This means that a system with natural supply of fresh air on the first floor will probably offer more comfort to the occupants.

8.2.3 Comparison between ventilation concepts
A comparison between different ventilation concepts has been made, especially regarding the effect of opening windows on the first floor on the yearly energy demand. The purpose of this comparison was to develop a ventilation system that offers a lot of comfort to the occupants, while at the same time significantly reducing the energy demand for space heating.

The following concepts have been compared:
1. Balanced ventilation on both ground floor and first floor, without keeping these two zones separated (as generally applied in passive houses);
2. Balanced ventilation on the ground floor and natural supply of fresh air on the first floor, without keeping these two zones separated;
3. A system with two compartments: balanced ventilation on the ground floor as well as the first floor, with a barrier (which is an air tightly connected door) between these two zones;
4. A system with two compartments: balanced ventilation on ground floor and natural supply of fresh air on the first floor, with a barrier in between (see figure 6).

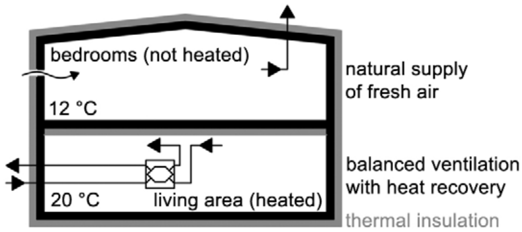

Fig 6. Ventilation concept with two compartments Balanced ventilation on the ground floor and natural supply of fresh air on the first floor

8.2.4 Conclusion
It was concluded that the concepts 1, 3 and 4 lead to comparable energy demands for space heating. Concept 2 leads to a higher energy demand. Using concept 4, the energy demand for space heating (on the ground floor) is least influenced by the ventilation behaviour on the first floor.
Improvement of comfort for the occupants is the most important goal of this research. Ventilation concept 4, with balanced ventilation on the ground floor and natural supply of fresh air on the first floor, offers the possibility to achieve this improvement of comfort, while at the same time significantly reducing the energy demand for space heating to an amount comparable to that of ventilation systems generally used in very energy efficient houses.

8.3 Reduction of infiltration and internal air flow
The targeted air tightness n_{50} is 1,2 h^{-1}, corresponding with the Dutch $q_{v;10}$ (the air permeability at a pressure difference of 10 Pascal) of 0,3 dm^3/sm^2. In order to take into account the influence of occupant behaviour (e.g. opening windows and doors), a 20 percent higher ventilation rate has been used in the Matlab Hambase model (n_{50} = 1,4 h^{-1}, $q_{v;10}$ = 0,36 dm^3/sm^2).
Of course attention must be paid to the air tightness of the constructions between the two compartments, but the air flow between the two zones cannot be completely prevented. It has been assumed that an air flow of 15 m^3/h will occur between the two compartments.

8.4 Total energy demand

Preliminary calculations have been made for both the small and the large type of dwelling. The efficiency of the heat recovery has been estimated at 90%. Also the space heating system has an estimated efficiency of 90%. Open windows on the first floor have been taken into account: windows are opened for 8 hours every day.

According to these calculations the chosen measures (thermal insulation, air tightness and ventilation concept) result in the following yearly energy use for space heating:

- Small type of dwelling: 186 m^3 (approx 6.590 cubic feet) of natural gas, or 20,5 kWh/m^2a;
- Large type of dwelling: 232 m^3 (approx 8.180 cubic feet) of natural gas, or 21,2 kWh/m^2a.

This is an exceptionally low energy use for renovated dwellings, even more so considering the fact that the thermal insulation measures to be taken are rather moderate. However, it should be noted that only part of the dwellings is heated, while the energy use for space heating is calculated based on the entire floor area. When the energy use is calculated based on the heated area only (which is the largest part of the ground floor, with a floor area of 48,4 m^2), the resulting energy use for space heating is as follows:

- Small type of dwelling: 37,6 kWh/m^2a;
- Large type of dwelling: 46,8 kWh/m^2a.

This project is still ongoing, and the effect of thermal bridges has not yet been taken into account in these preliminary calculations. Therefore it is expected that the final calculations will show a higher energy use for space heating.

8.5 Achieving a zero-energy heating balance

The before mentioned preliminary calculations show an expected energy consumption for space heating of 232 m^3 of natural gas for the large type of dwelling. Under the current situation this would represent a cost of about € 140 per year (€ 12 per month) for the occupants.

232 m^3 of natural gas represent about 2.300 kWh of energy. This amount of energy can easily be generated by mounting a photovoltaic system on the roof (approximately 25 m^2 of PV panels would be sufficient). Unfortunately, the cost of a PV system is rather high. Other systems could also be considered; however, the question is whether a cost of only € 140 a year (and for the small type of dwelling even less, about € 110 a year) justifies further effort in reaching the zero-energy level.

9. Conclusions

By using the developed approach to renovate Nemavo-Airey dwellings in the Netherlands, many significant improvements can be made to these houses.

Firstly, comfort for the occupants can be significantly increased. Dwellings are enlarged by placing an addition at the back of the houses. The indoor climate is improved by adding thermal insulation and by improving the ventilation system. Also sound insulation is improved. The available flexibility and adaptability is also an improvement.

Regarding the ventilation system, it has been found that the generally used balanced ventilation system in the entire house is not the best option here. By using natural supply of fresh air in the bedrooms, occupant needs are better met. Dividing the house in two compartments makes it possible to do this without making concessions regarding the energy demand for space heating.

Secondly, the possibility to convert the small type of dwelling into the large type of dwelling at a later time increases the life expectancy of the dwellings.

Thirdly, the added thermal insulation and the reduction of ventilation and infiltration losses result in a very low energy demand of 20,5 kWh/m^2a for the small type of dwelling, and 21,2 kWh/m^2a for the large type (calculated based on the entire floor area, including the non heated area). This energy demand can be generated sustainably by placing photovoltaic panels on the roof, thus reducing the energy demand to zero. Unfortunately the costs of photovoltaic panels are still very high. Therefore the on-site photovoltaic generation of all energy required for space heating is not an economically feasible option at the moment.

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