Cost effective thermal insulation in housing

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ABSTRACT: In The Netherlands low energy building is being stimulated by government regulations ordering minimum energy performance requirements. For obtaining a building permit there must be proof of a certain energy performance. This is done using the EPW programme. In this program the energy related building components are valued and expressed in one figure. As by 01-01-2006 this figure should not be higher than 0,8.

The disadvantage of this system is that the occupant is not involved in this process, while it is the occupant who is paying the energy bill for the rest of his life. In order to make the occupant aware of the relation between energy performance and energy cost both are expressed in Euros.

In this research the main questions are:

1. What is the relation between extra thermal insulation cost and return on investment over a 25-year period?
2. What is the influence of the occupant's activities on fossil energy cost?
3. What is the influence of the existing orientation of the dwelling on the fossil energy consumption?

To answer these questions the "Matlab" dynamic calculation program is used. Items like thermal insulation, window performance, and surface of windows, orientation and occupant behavior have been calculated for a 25-year period.

Conclusions:

1. Depending on the occupants activity an extra investment on energy performance of € 3000, = will be cost effective within a 20 year period.
2. If occupants are active in using shading devices, temperature control and ventilation an extra 10% reduction of fossil energy cost can be achieved.
3. For east or west orientation the use of fossil energy can vary up to 30% compared to a south orientation.

Keywords: investment, orientation, occupant behavior

1. INTRODUCTION

As part of the goal set for reducing the emission of greenhouse gasses the Dutch government stimulates the development of low-energy housing construction. The results should lead to a lower demand for natural gas required for heating of houses and hence a lower emission of CO^2.

This goal is achieved by requiring a minimum performance for all energy related building components. The maximum U-value for the ground floor as well as the external walls and the roof is set at 0,4 W/m²K. Moreover the combined performance of all energy related components must be calculated using the EPW program [1]. Among other things this program calculates the combined influence of orientation, heat capacity, glass surface, air tightness, heating system, ventilation system and active solar energy systems. The result of these calculations is expressed in one figure which is increasingly further tightened up. By 1 January 2006 this figure is set at 0,8 in contrast to the pervious figures of 1,4 in the year 1995 and 1,0 in the year 2000. With this heavier requirement the calculation programme has also been adapted and other energy related components like sunblinds and self-regulating air supply gratings have been implemented.

Market parties must find an answer to meet these always-stricter becoming requirements in case they want to obtain a building permit for their project. The disadvantage of this strategy is that it has an impact on the construction costs. Manufacturers must continue to develop their products to higher standards and prices go up.

By the time the construction costs stabilize there is a next reinforcement of the building code and the whole cycle starts again. Eventually the purchaser pays the incremental costs and house prices will rise more and more.

In 1996, SEV and Novem call upon market parties to propose their projects as an example for low-energy building. In 1997 50 projects received the example status and have been built. Three years later, in 2000, the results of the projects have been evaluated and published [2]. What is notable to these results is that there is much information on the way the low EPW value has been gained, but not with which quantity the use of earth gas for heating has been reduced.

For this reason it is not possible to determine what the reduced emission of CO^2 for a period of time is. The publication has been mainly meant to show market parties which resources make low-energy building possible.

2. STARTING POINT: A STANDARD HOUSE

2.1 Characteristics of the standard house

As a main point for the study into cost-effective insulation the most attentive passive design characteristics from the example projects have been processed in a house design, which meets minimum requirements of the Dutch building code [fig. 1].

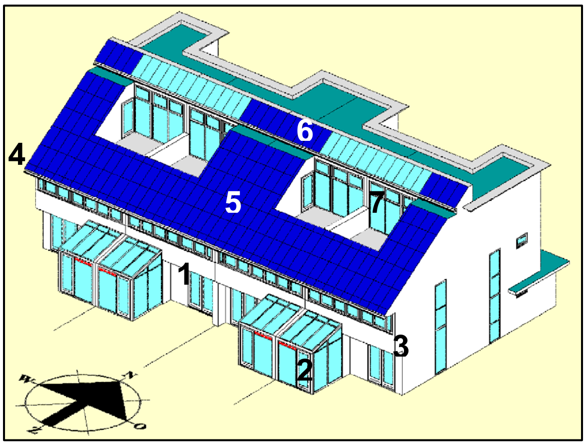

Figure 1: the south facade of the standard dwelling.

In order to easily examine the influence of heat insulation, without having to change the buildup of the outside walls, the insulation parcel has been placed on the outside of the wall. This parcel is finished with plasterwork. The characteristics of this façade are related to the southern path of the sun.

The following numbers indicate which components have been incorporated in the design of the south façade:

1. A high glass surface to outside wall ratio;
2. A greenhouse;
3. An overhanging first floor;
4. Deep roof gutters;
5. Photovoltaic energy;
6. Solar collectors;
7. A daylight distribution channel;

The characteristics of the street façade are related to the northern orientation and the absence of solar gains. This is combined with the fact that in Dutch society the emphasis lies on a strong separation between public space and the private living. In the floor plan the living area is situated at the back yard.

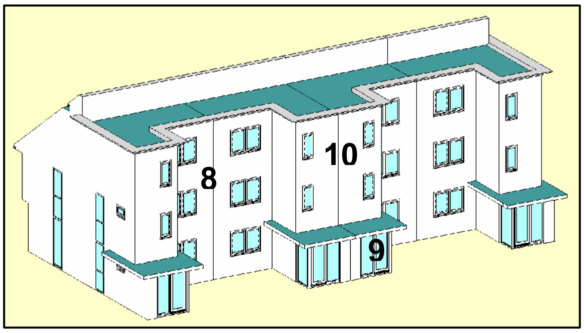

Figure 2: the north façade of the standard dwelling.

The following numbers indicate which components have been incorporated in the design of the north façade [fig. 2]:

8. A low surface glass to outside wall ratio;
9. A enclosed porch at the entry;
10. To ensure short piping toilet, bathroom, kitchen and installation spaces are positioned close to each other;

One of the main points with passive design strategies is the manner on which sunlight is allowed into the dwellings during the seasons. During the summer there's need for low indoor temperatures and no direct sunlight radiation whereas during winter the opposite is true. These characteristics can be seen in the cross-section of the standard house [fig. 3].

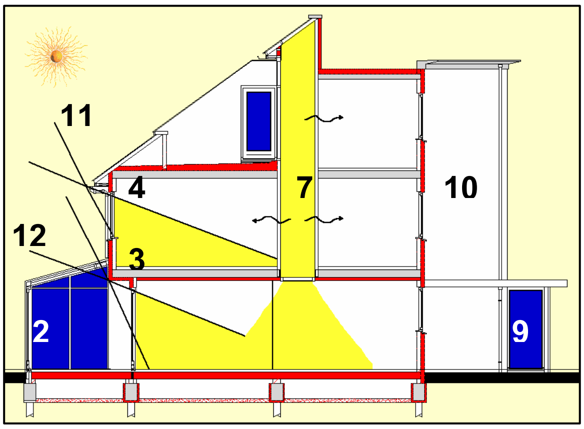

Figure 3: a cross-section of the standard dwelling.

The following numbers indicate which components have been incorporated in the cross-section:

11. Maximum inclination of the sun on 21 June is 75 degrees (Netherlands);
12. Maximum position of the sun on 21 December is 28 degrees (Netherlands);

Also a number of components, which have been appointed earlier, are indicated in the cross-section.

The declared position of the sun applies to the village of De Bilt where the KNMI (Royal Dutch Meteorological Institute) is established. The institute has latitude of 5°11'00.00" East and a longitude of 52°06'59.99" North.

The purpose of the daylight distribution channel is to allow daylight to penetrate deep into the center of the house. In this research this concept is introduced based on project Westerpark in Breda [3]. The effectiveness of this light well has not been analyzed and needs further testing. Because of the higher indoor temperature in the light distribution channel, there's less energy needed during cold periods to warm up adjacent spaces. During summer this channel can be shaded with outdoor sunblinds to avoid unpleasant high indoor temperatures.

2.2 Heat capacity and air-tightness.

In order to examine the heat capacity of the external surfaces, the U-values meet the maximum values as set by the Dutch building code [table 1].

Number	Component	U-value (W/m²K)
1	ground floor	0.4
2	external wall	0.4
3	inclining roof	0.4
4	flat roof	0.4
5	Glass	1.2

Table 1: maximum U-values of the standard house.

In comparison with for example the Scandinavian countries these maximum U-values are not that high. This is the consequence of the mild sea climate in the Netherlands, as a result of which Dutch contractors are not used to build airtight houses.

In the EPW programme the Qv:10 factor, which indicates the air-tightness, is 1.0 $dm^3/s.m^3$. If both the architect and the contractor pay special attention to the connection of the joints, this factor can be reduced to 0.625 $dm^3/s.m^3$. In this case a air-tightness test at completion should be mandatory.

2.3 Energy usage of the standard house.

The energy usage of the standard house is calculated using the programme MatLab v.6.5 and the rack module HamBase [4]. The majority of Dutch houses are row houses. For this reason the demand for natural gas, needed for heating, is calculated for a cluster of 2 intervening and 2 end houses [fig. 4].

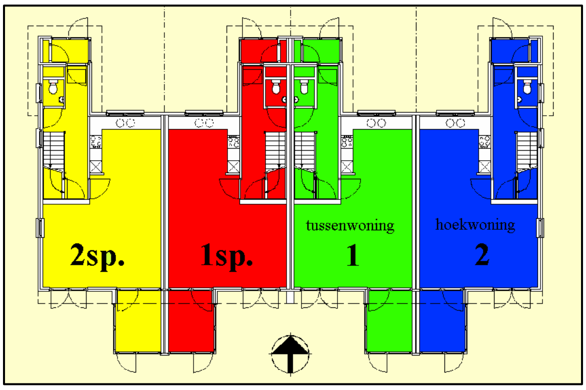

Figure 4: ground floor plan of 4 examined standard houses.

Calculations have been carried out for an optimum orientation with the rear facade facing south [table 2].

Number	Natural gas (m^3/year)	Deviation (%)
1	763	0%
1sp	760	-0.5%
2	935	22.5%
2sp	955	25.0%

Table 2: energy usage of 4 examined standard houses.

In order to run the rack module HamBase additional information is needed. For this reason the following information is determined:

- The year of reference is 1974;
- The zones within the standard house;
- Obstacles for daylight entrance;
- The output of the heat recovery unit is 72%;
- The occupants profile by day, evening and night;

3. RESEARCH DESIGN CHARACTERISTICS

3.1 Introduction.

The general idea concerning investments in low-energy houses is that the costs do not even out against the profits. On an already expensive market it is difficult to put even more stress on the housing prices. At present a low-energy house is less important to purchasers than for example larger living spaces and more daylight.

It is the responsibility of developers, architects and contractors to persuade the investor for an extra investment will lead to much lower monthly charges and a higher market value of their house. Eventually the purchaser is only, by means of money, sensitive for argumentation. For this reason this research has been focused on the ratio between the investment and the time a measure repays itself.

3.2 Enumeration of all researches carried out.

The research into the design characteristics can be divided in 4 main groups and 19 subgroups. The main groups are:

1. Research into thermal insulation;
2. Passive solar design measures;
3. The influence of occupants behavior;
4. Orientation versus energy;

In this paper subgroups of numbers 1,3 & 4 are addressed. The combined results of all examinations will lead to the conclusions mentioned in chapter 8.

3.3 Enumeration of not commented research.

The research into passive solar design measures can be divided into the following subgroups:

- Surface ratio of outside wall & glass;
- An overhanging first floor;
- Deep roof gutters;
- The daylight distribution channel;
- The separating wall between 2 dwellings.

3.4 Energy savings versus the price of natural gas.

In order to compare the energy reduction of a measure with the incremental costs a forecast for the increasing energy prices is made. For this research the price of natural gas without taxes for 01-01-2005 is determined at € 0.429 / m³.

The forecast is that the price of natural gas will approximately increase with 0.7% a year [5]. In the investment comparison net prices will be used for both energy as well as insulation materials.

4. THERMAL INSULATION RESEARCH

4.1 Introduction.

In order to be able to properly examine the influence of several variables, the design of the standard house has been set up in such a way that modification of e.g. the heat insulation can carried out without significant architectural changes.

The research into thermal insulation can be divided into the following subgroups:

1. Insulation ground floor;
2. Insulation outside wall;
3. Glass quality;
4. Surface ratio wall/glass;
5. Insulation first floor;
6. Overhanging first floor;
7. Separation wall light channel;
8. Insulation terrace on roof;
9. Insulation inclined roof;
10. Insulation flat roof;

4.2 Heat insulation of the outside wall (nr. 2).

In this chapter the influence of the heat insulation on the outside wall is discussed [fig. 5]. As heat insulation material EPS20 parcels are used with a thickness of 100mm. The U-value is 0.35 W/m²K.

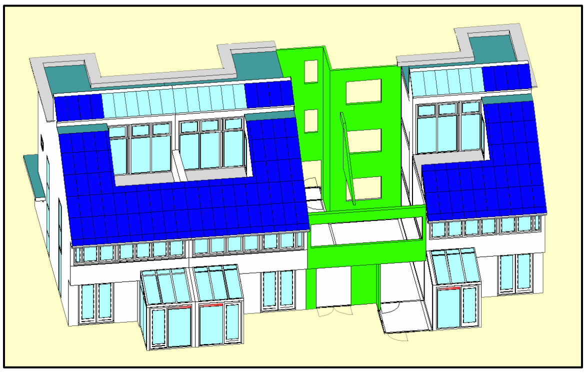

Figure 5: examined heat insulation of outside wall.

4.3 Calculations.

For 10 different variables of heat insulation thickness the influence on the need for earth gas is calculated. The results are compared with the needs of the standard house [table 3].

4.4 Investment.

The period for which the investment comparison is made is 25 years. This period corresponds with the goals set by the Dutch government for reducing the emission of green house gasses in 2030. An average Dutch family moves after 7 years. It is assumed that, not fully repaid investments, will be discounted in the market value of the house. The total surface of heat insulation on external walls is 113.5 m² [table 3]. The investment is based on material prices only (no taxes). It is assumed that costs for production, transport and placing the parcels remain unchanged.

Thickness (mm)	Natural gas (M³/year)	Percentage (%)
100	763.5	0%
120	739.8	-3.1%
150	715.6	-6.3%
200	690.4	-9.6%
300	664.3	-13.0%
400	**651.4**	**-14.7%**
500	643.5	-15.7%
600	638.6	-16.4%
700	635.7	-16.7%
800	631.8	-17.3%
900	629.7	-17.5%

Table 3: reduction percentage natural gas consumption in relation to thermal insulation thickness of the outside wall.

Thickness (mm)	Investment 113.5 m² (€)	Incremental costs (€)	Natural gas savings (25 years)
100	€ 423, -	€ 0, -	€ 0, -
120	€ 508, -	€ 85, -	€ 277, -
150	€ 635, -	€ 212, -	€ 560, -
200	€ 847, -	€ 423, -	€ 856, -
300	€ 1.270, -	€ 847, -	€ 1.160, -
400	**€ 1.693, -**	**€ 1.270, -**	**€ 1.310, -**
500	€ 2.117, -	€ 1.693, -	€ 1.403, -
600	€ 2.540, -	€ 2.117, -	€ 1.460, -
700	€ 2.963, -	€ 2.540, -	€ 1.494, -
800	€ 3.387, -	€ 2.963, -	€ 1.539, -
900	€ 3.810, -	€ 3.387, -	€ 1.564, -

Table 4: Investment cost insulation of the walls and natural gas savings over a 25 year period.

4.5 Selection for heat insulation of the outside wall.

From tables 3 and 4 can be derived that in the Dutch sea climate for a standard year the optimal heat insulation thickness is 400mm. Within a period of 25 years the energy savings (-14.7%) are just less than the investment. The profit in this case would be approximately €40, -.

On itself this amount is negligible, but at purchase this investment produces a tax advantage. Meanwhile the monthly costs for energy are lower than for the standard house.

4.6 Summary thermal insulation research.

In sum this research has been conducted for 10 different parts of the outside surface of the house. The investigation has been conducted in the same manner like described in chapter 4.2 up to 4.5. Only the performance of the subgroups and the incremental costs are mentioned [table 4].

Description	Perc. (%)	Incremental costs (€)
1. Insulation ground floor	-10.9%	€ 363, -
2. Insulation outside wall	**-14.7%**	**€ 1.270, -**
3. Glass quality	-3.8%	€ 191, -
4. Surface ratio wall/glass	-2.0%	- € (Less)
5. Insulation first floor	0.2%	- € (Less)
6. Overhanging first floor	-3.5%	- € (Less)
7. Sep. wall light channel	-1.7%	Unknown
8. Insulation terrace on roof	-2.8%	€ 48, -
9. Insulation inclined roof	-0.8%	€ 73, -
10. Insulation flat roof	-4.8%	€ 314, -
Total:	**-44.8%**	**€ 2.259, -**

Table 5: Summary thermal insulation research.

** Because of the complex character of the investment calculations it is assumed that some incremental costs will be omitted against each other. To compensate eventual deviations 30% extra costs will be added up in chapter 8.*

5. OCCUPANTS BEHAVIOUR

5.1 Introduction

There are three factors that determine the total energy demand for heating a house. These factors are: the weather, the architectural quality of the house and occupants behavior. The first one we can't influence, the second we can [chapter 4]. The third one may proof to be to be the most important factor.

Houses can be built with extremely high heat insulation values and good air-tightness, but when the occupant is not aware how his behavior influences the energy usage, this investment makes no sense. Therefore the usage of three installation appliances is selected to examine this influence. In addition the output percentage of the heat-recovery unit of the ventilation system is examined.

The 4 subgroups in this research are:

1. Control of the sun blinds;
2. Control of the thermostat;
3. Using the bypass possibility on the heat recovery unit of the ventilation system;
4. Output percentage of the heat-recovery unit.

5.2 The bypass on the heat recovery unit.

One of the big disadvantages of heat-recovery systems for ventilation is that they only work properly when the building is airtight. This means that also doors and windows should remain closed to prevent the needed heat from escaping.

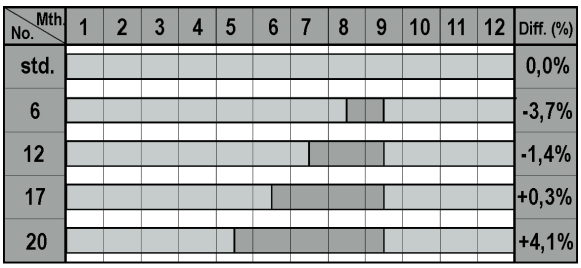

Figure 6: energy loss with doors and windows opened for 1, 2, 3 & 4 months

During warm periods in spring, summer and fall the occupant wants to open doors and windows. In the research is examined during which periods the occupant can do this, without losing more than 5% energy for heating. In these calculations periods of 1, 2, 3 and 4 months are examined [fig. 6].

5.3 Conclusion.

From figure 6 can be derived that it is even possible to save some energy with opening doors and windows. However, it is not realistic to expect occupants to behave in the manner, which is needed to achieve this. There are just too many factors to consider. It is easier to advise an occupant that doors and windows can be opened between the 15th of May and the 15th of September. In these three months the energy demand for heating in the reference year 1974 is an extra 0.3%.

What is notable is that in the year of reference 1974 the circumstances where such that it is apparently necessary, from an energetic point of view, to keep doors and windows closed after the 15th of September. A separate research is needed to predict how this can be coordinated in years with different weather profiles.

5.4 Summary of research into occupant's behavior.

This research has been conducted for three other subgroups. The results are mentioned in table 6.

Description	Perc. (%)	Energy savings (25 years)
11. Control of the sun blinds	-3.0%	-€ 267, -
12. Control of the thermostat	-6.9%	-€ 615, -
13. Bypass heat-recovery unit (open doors & windows)	**0.3%**	**€ 27, -**
14. Output percentage of the heat-recovery unit (72)%	0.0%	€ 0, -
Total:	**-9.6%**	**-€ 855, -**

Table 6: Summary research occupants' behaviour.

From table 6 can be derived that people can save money if they would be more aware to the use of their installations. The amount saved for only this subgroup is not that high, but the real advantage is that the indoor temperature will become more pleasant and additional cooling is not needed.

Manufacturers of heat-recovery units always give up laboratory output (±95%). This percentage does not include control losses of the total system. Therefore a realistic percentage is about 72%.

6. THE OPTIMIZED HOUSE.

6.1 Introduction.

All the selections made in chapter 4 & 5 are combined in one calculation. The results indicate the total effect on the demand for earth gas needed for heating the optimized house during a standard year. When added up the results, which are mentioned in these chapters, should lead to a -54.4% reduction in using earth gas for heating.

6.2 Calculations.

The results of the combined calculation are mentioned in table 7.

Number	Standard (M³/year)	Optimized (M³/year)	Reduction (Opt/std)
1	763	427	-44.0%
1sp	760	426	-43.9%
2	935	498	-46.7%
2sp	955	501	-47.5%

Table 7: need for earth gas in the 4 optimised houses.

6.3 Conclusion.

From the results mentioned can be derived that the calculated reductions for individual examinations cannot be added up. The combined result of all selections is not –54.4% but –44.0%. The difference of 10.4% can be explained, because the selection of one measure can influence the result of another.

When the heat insulation of the outside wall is increased, the influence of for example thermostat control by the occupant decreases.

The deviation of the end houses is less than mentioned in table 2. These houses need approximately 17% more energy for heating.

7. ORIENTATION

7.1 Introduction.

All the calculations for the previous described research are made with the rear façade facing south. In urban development plans this ideal orientation does not exist frequently. Therefore the influence of 4 additional orientations is examined [fig. 7].

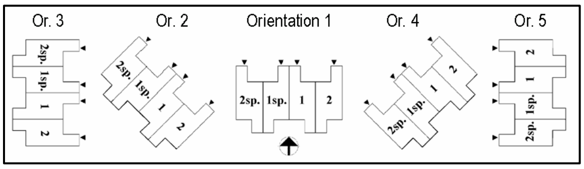

Figure 7: examined orientations.

7.2 Calculations.

The energy usage for orientations 2 to 5 is made for the optimized house [table 8].

Nr.	Or. 3	Or. 2	Or. 1	Or. 4	Or. 5
1	+31.9%	+11.5%	427 m³	+11.4%	+31.9%
1sp	+36.0%	+14.1%	426 m³	+ 8.7%	+28.6%
2	+17.5%	+ 4.4%	498 m³	+12.4%	+30.9%
2sp	+33.1%	+14.3%	501 m³	+ 2.1%	+13.6%

Table 8: energy usage per orientation for 4 houses.

Nr.	Or. 3	Or. 2	Or. 1	Or. 4	Or. 5
1	+27.6%	+ 7.5%	427 m³	+7.4%	+27.7%
1sp	+31.7%	+10.0%	426 m³	+4.8%	+24.5%
2	+10.1%	- 2.8%	498 m³	+4.7%	+22.8%
2sp	+25.0%	+ 6.6%	501 m³	- 5.1%	+ 6.3%

Table 9: energy usage for a thickness of 900mm.

Additional calculations have been made to examine if it is possible to reduce the energy usage of houses with less ideal orientations to the level of orientation 1. The thickness of the heat insulation parcel is with steps of 100mm increased. The results show the percentage for a thickness of 900mm. Orientation 1 has a standard thickness [table 9].

7.3 Conclusion.

From the results mentioned in table 8 & 9 the following conclusions can be derived:

- Houses at the end of a row experience more advantage with an east or west orientation than a row house;
- Even an insulation thickness of 900mm cannot lower the energy usage of houses with orientation nr. 2 – 5 with more than 4%.
- The effect of a morning or evening sun is evident for the end houses and Or. 3 & 5.

8. CONCLUSION

In this research 400 mm of thermal insulation in housing is found to be cost effective for a period of 25 years. The embodied energy for the thermal insulation is not taken into account.

Positive occupant behavior can result in an extra 10% saving of fossil energy; negative occupant behavior can destroy all savings.

The orientation of a building can influence up to 30% the fossil energy demand.

9. ACKNOWLEDGEMENT

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10.REFERENCES

[1] EPW calculations NEN 5128 (housing)

[2] Nationaal Dubo Centrum & Stuurgroep Experimenten Volkshuisvesting (SEV), Duurzaam Bouwen: *Een kwestie van willen en weten*, Rotterdam, The Netherlands, 2000, ISBN 90-5239-161-0 (in Dutch).

[3] De Zon in stedebouw en architectuur, Novem, 2000, DV 1.1.136 (in Dutch)

[4] HamBase is developed by Prof Dr Ir M.D.H. de Wit**,** Faculty of Architecture, Eindhoven University of Technology, Eindhoven, The Netherlands.

[5] Research by ECN (energy research center Netherlands) and RIVM (environmental agency).