DEMAND CONTROLLED VENTILATION APPLICABLE FOR ANY AIR TIGHTNESS LEVEL AND OCCUPANCY?

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ABSTRACT

The Dutch housing stock consists for about 70% of single family houses with an average N_{50} of about 7-9 ACH and for 30% of apartments with an average N_{50} of about 3-4 ACH.
New single family houses are much more airtight. In the period 1970 to 2000 the air tightness increased to an N_{50} of about 3 - 4 ACH. Apartments have nowadays about the same or a slightly better air tightness then before 1970.

Another trend is the downward tendency of occupant numbers per dwelling. During 1982 to 2000 in the Netherlands the average number of occupants per dwelling decreased from 2.8 with 21% to 2.3 persons per dwelling.

These two trends can have an impact on the choice of a ventilation system when dwellings from a certain period need to be retrofitted. The question is e.g. whether demand controlled ventilation has an added value depending on the air tightness and occupancy of the dwelling.

In the framework of the RESHYVENT project this study comprises COMIS simulations to investigate the relation between occupancy/air tightness and demand controlled ventilation. Based on indoor air quality (IAQ) and energy consumption a comparison has been made between the situation with the exhaust continuously at 21 dm^3/s and all supply provisions closed and the situation that a ventilation strategy such as demand controlled ventilation is applied.

The paper gives a positive answer on the applicability of demand controlled ventilation regardless occupancy and air tightness. Even at low air tightness (N_{50}>16 ACH), from IAQ point of view demand control is interesting. With internal mixing (e.g. open doors and/or air heating systems), in combination with supply provisions closed, pollutants can be reduced to the same levels as with demand control, however this can also lead to a undesired spread of local pollutants. Through a good distribution of the supply air, demand control does not result in an increase of the ventilation compared to the situation with supply provisions closed. On the other hand, depending on the occupants' behavior, significant energy savings are possible.

KEYWORDS

Occupancy, air tightness, indoor air quality, energy use, retrofitting, demand control

INTRODUCTION

Since more than 20 year data from pressurization tests in the Netherlands have been gathered in a database, see Cornelissen et al (1994). At present in total about 700 houses are available within the database. The data about air tightness in this article are derived from this database.
The Dutch housing stock consists for about 70% of single-family houses with an average N_{50} of about 7-9 ACH and for 30% of apartments with an average N_{50} of about 3-4 ACH. New single-family houses are much more airtight. In the period 1970 to 2000 the air tightness increased to an N_{50} of about 3 - 4 ACH. Apartments have nowadays about the same or a slightly better air tightness then before 1970.
Another trend is the downward tendency of occupant numbers per dwelling. During 1982 to 2000 the average number of occupants per dwelling decreased with 21% from 2.8 to 2.3 persons per dwelling in the Netherlands.
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MODELLING

Comis

Within COMIS two models have been used. The first model represents a typical single family dwelling, see figure 1. The second model represents the lay-out of a typical apartment, see figure 2.

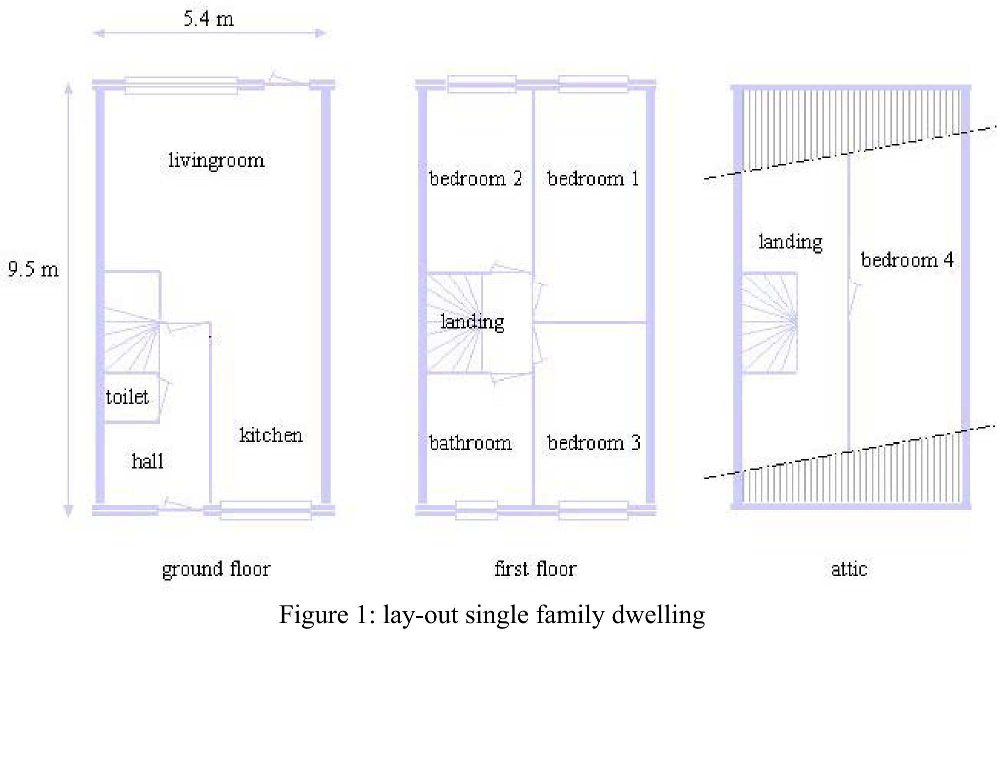


Figure 1: lay-out single family dwelling

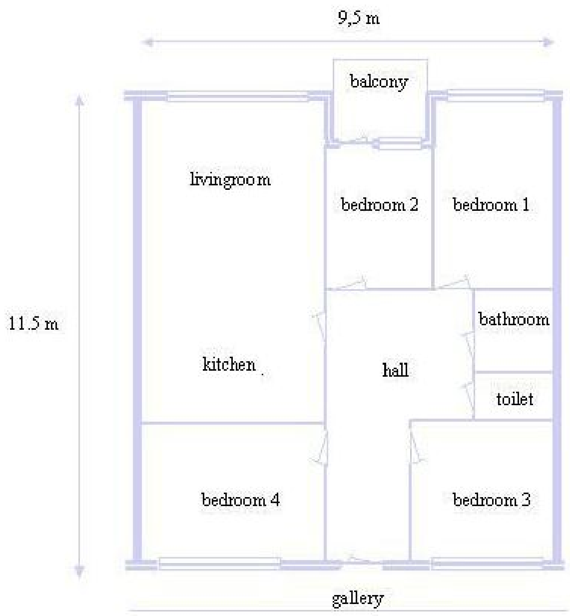


Figure 2: lay-out apartment

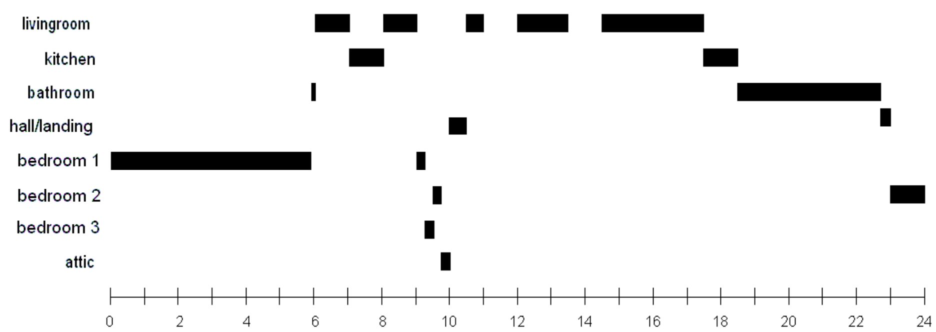
COMIS calculations have been executed, coordinated by VentControl. This is a software program that permits the simulation of various control aspects e.g. based on presence, time schedules and IAQ.

By using the condensed TNO reference year, which consists of 3 days for each season, a typical Dutch heating season (210 days) has been simulated. Table 1 gives the occupant presence distribution schemes used.

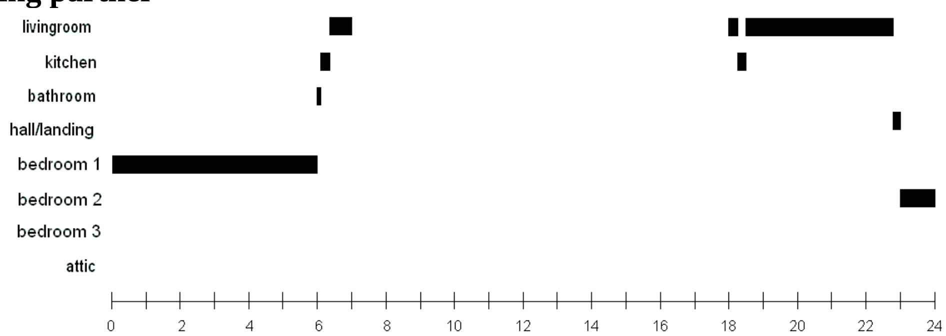
TABLE 1

Presence distribution schemes for a 4 persons family

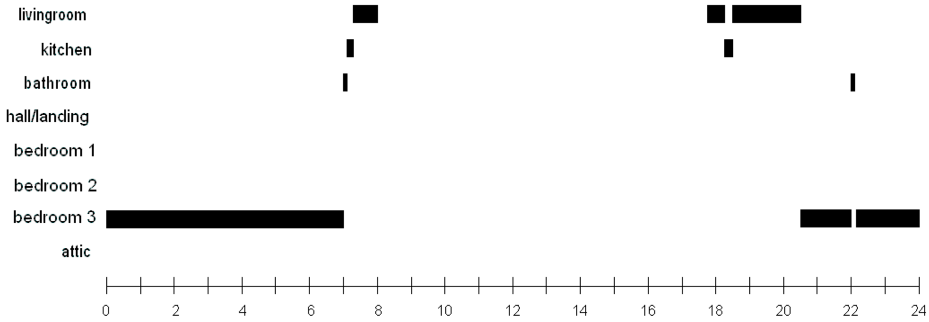
Housekeeping partner



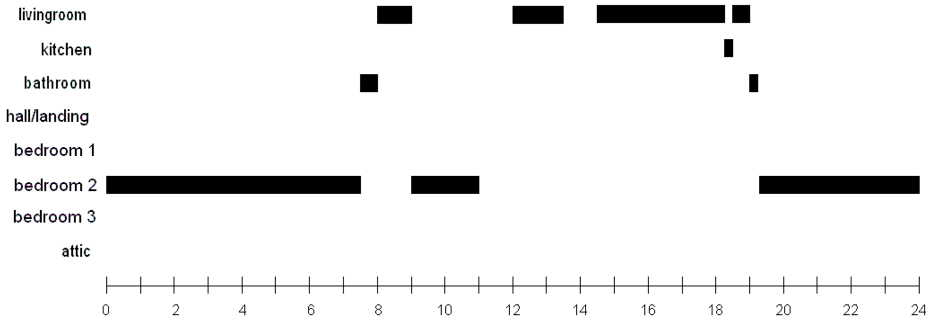
Working partner



Schoolchild



Baby



Air leakages

The distribution of air leakages over the building envelope is shown in table 2. This distribution is derived from de Gids (1981) and Cornelissen (1994). It remains relatively constant for different air leakages. Therefore in all simulations the same distribution of leaks has been assumed.

TABLE 2
Relative leakage of several building elements in the Netherlands

$q_{v,10}$ [dm^3/s]	N_{50} [ACH]	ground floor [%]	Walls [%]	Roof [%]
30	1	17	26	57
100	4	12	28	60
150	6	15	30	55
200	8	17	28	55
400	16	17	26	57

Output

For a broad understanding the results of the COMIS simulations are expressed in (1) time exposed to CO_2 levels higher than 1200 ppm (Dutch standard $\Delta CO_2 < 850$ppm) in combination with the maximum occurring CO_2 level and (2) in the "low ventilation index" (lvi) (de Gids, 1992). The lvi gives an indication of the air quality, the time and extend to which IAQ is insufficient, over a certain time frame, e.g. the heating season. It is defined as the time integration of the normalized ventilation below a value of one. In this paper the normalized effective ventilation is scaled in such a way that at a value of one is equal to a CO_2 rise of 850 ppm above outside. Figure 3 gives an example of a histogram of the normalized ventilation for an lvi of 0.005. During 2% of the time the ventilation is too low. The CO_2 concentration can rise up to two times the boundary limit (q_{en}=0.5). But a lvi of 0.005 could also characterize a situation in which during 4% of the time the ventilation is limited to a normalized effective ventilation of 0.75 (CO_2 concentration maximal 1/0.75=1.33 times the boundary limit). Seen the possible combinations of time and CO_2 levels a lvi of 0.005 can be considered as a good choice for boundary limit.

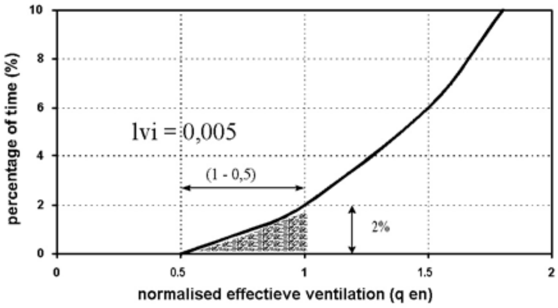


Figure 3: histogram normalized effective ventilation

SIMULATION RESULTS

First the question “Is a ventilation strategy required?” is answered. These simulations have been executed with the supply provisions closed and are compared with demand control. Second the effect of manual window airing is compared with demand control. The following parameter ranges have been used:

TABLE 3
Parameter ranges for simulations

Parameter	**Minimum**	**Maximum**
Air tightness N_{50} [ACH] ($q_{v,10}$ [dm^3/s])	1 (30)	16 (400)
Number of persons	1	4
Supply provisions	closed	Open
Exhaust flow rate [dm^3/s]	21(10.5*)	42
Exchange through doors	doors closed	doors open
Control	no	demand controlled

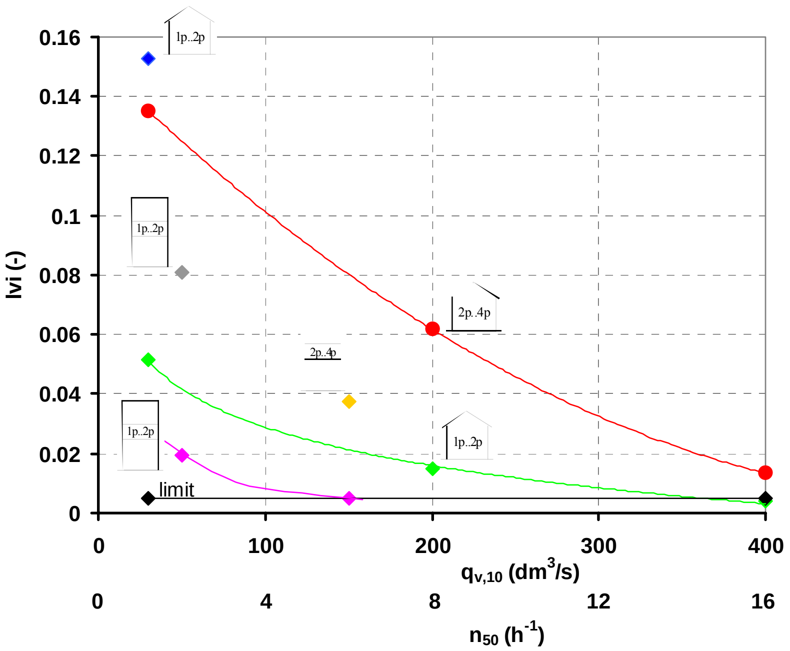
*Demand control can reduce exhaust up to this minimum flow.

Supply provisions closed versus demand control

Indoor air quality

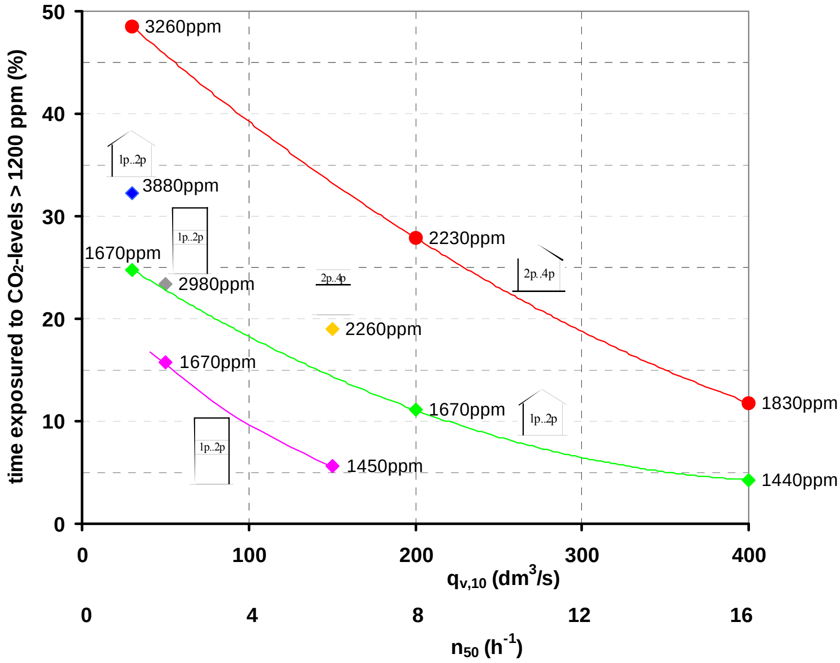
The simulation results for supply provisions closed are shown in Figure 4 (low ventilation index, lvi) and Figure 5 (CO_2 > 1200 ppm). Pictograms indicate whether data concern a single-family house or an apartment. Single points indicate situations with bedroom doors closed, lines with bedroom doors ajar. In Figure 5 the maximum CO_2 levels are listed. These values are reached in the bedrooms and constitute the dominant factor for the lvi. An important conclusion which can be drawn is that ventilation strategies are required to obtain a suitable air quality, even in houses with worse air tightness (up to N_{50} = 16 ACH) and habituated by only one person. Due to the fact that all leakages are localized in the walls, and thus infiltration air flows more directly through the occupied zones, apartments render a better IAQ than single-family houses with the same air tightness.

In practice the IAQ can differ due to the effect of open doors. Figure 6 shows the effect of mixing between rooms and the landing. By opening the bedroom doors with a few centimeters, which is simulated by an air exchange of 2.3 dm^3/s, the lvi is largely improved (but still insufficient as is shown in figure 4 and 5). This is a result of a better distribution of the infiltration air. With internal doors fully opened a good IAQ can be maintained. This explains also why with an air heating system, with high internal flows, good results concerning IAQ can be obtained. Disadvantage of this system, which is widespread in the US, is the spread of pollutants (e.g. cigarette smoke). Data for demand control are not shown in figure 4 and 5, but are below lvi=0.005.



1p..2p: occupancy by 1 to 2 persons using different bedrooms
2p..4p: occupancy by 2 to 4 persons, of which 2 persons use the same bedroom
lines: situations with bedroom doors ajar
point: situations with bedroom doors closed

Figure 4: supply provisions closed, air quality expressed in normalized effective ventilation (lvi)



1p..2p: occupancy by 1 to 2 persons using different bedrooms
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lines: situations with bedroom doors ajar
point: situations with bedroom doors closed

Figure 5: supply provisions closed, air quality expressed in time exposed to $CO_2 > 1200$ ppm, maximum CO_2 value is listed

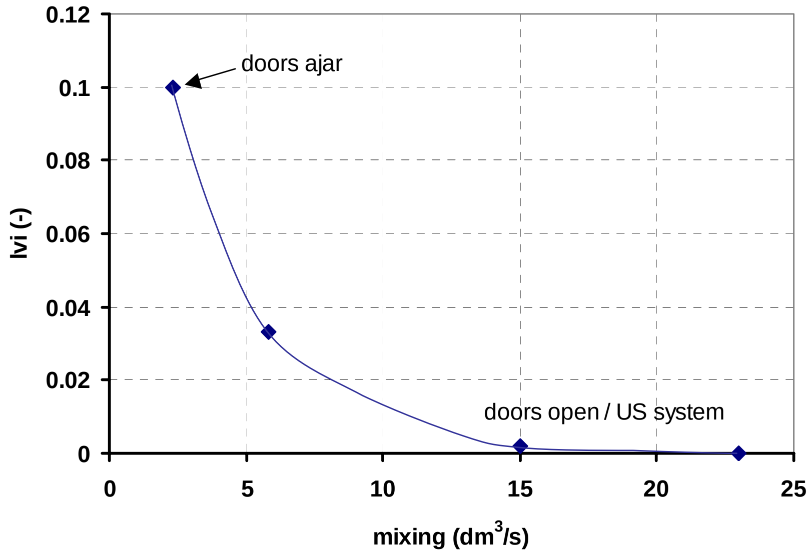

Figure 6: effect of mixing (air exchange) between rooms and the landing on air quality (lvi)

Energy

The energetic consequences are shown in figure 7. The energy use is the energy required to warm up the air with 13 K during the heating season. The figure clearly shows that air tightness is a prerequisite for low energy consumption. The differences between demand control and supply closed are small. Especially a better distribution of the infiltration air is apparently reached.

As an indication it is mentioned that the absolute minimum ventilation requirement for CO_2 removal, for a family with 4 persons and taken the presence and activities in the different rooms as given in Table 1, is about 17 dm^3/s.

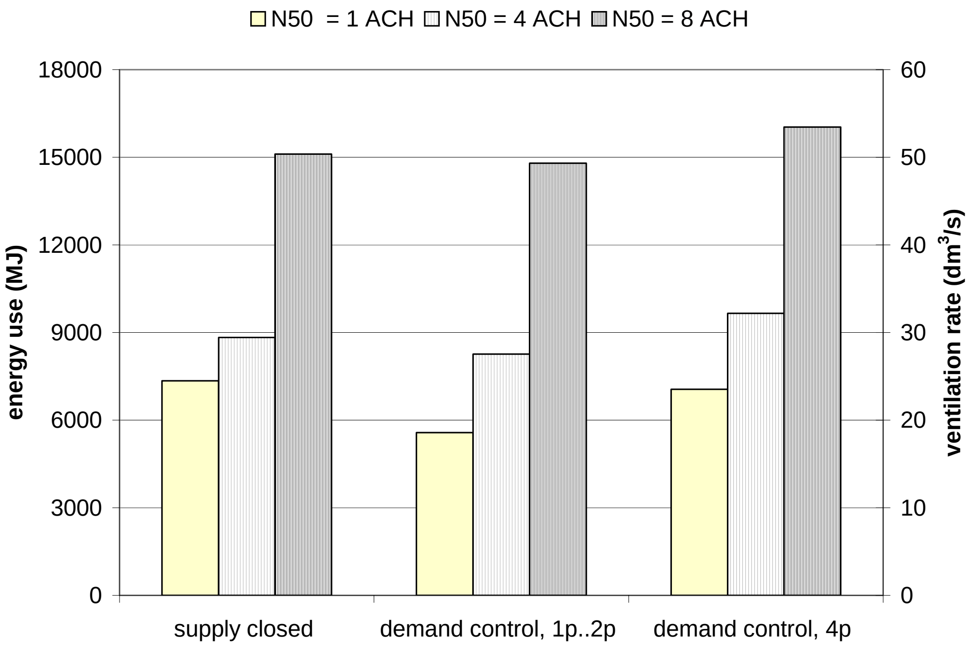

Figure 7: energetic effects of ventilation strategies for different air tightness

Manual window airing versus demand control

COMIS calculations have been made for manual window airing in the bedrooms with exhaust at 21 and 42 dm^3/s during the night. Manual window airing implies here that during the night the bedroom supply provisions are set on the nominal capacity for 1 and 2 persons bedrooms: 7 and 14 dm^3/s respectively at 1 Pa pressure difference. The results are shown in table 4.

TABLE 4
Effect of window airing in bedrooms on average ventilation and lvi (N_{50}=4 ACH, 4 persons)

	Supply closed	**Window airing in bedrooms, exhaust**		**Demand control**
		21 dm^3/s	**42 dm^3/s**	
Heating season average ventilation [dm^3/s]	30.9	36.5	40.7	33.8
lvi	0.1	0.0292	0.0036	0.003

The main improvement of demand control compared to the window airing is that the exhaust during the night is controlled between 10.5 and 42 dm^3/s. Thus a better or comparable IAQ is reached at a lower overall ventilation and corresponding energy use.

CONCLUSIONS

Indoor Air Quality:

- The low ventilation index (lvi), or the amount of hours the CO_2 concentration exceeds 1200 ppm, mainly is determined by the hours spent in the bedrooms.
- Ventilation strategies (demand control, mixing, manual) are required to obtain a suitable air quality even in houses with worse air tightness (up to N_{50}=16 ACH) and habituated by only one person.
- Due to the fact that all leakages are situated in the walls apartments render a better IAQ than single-family houses with the same air tightness.

Energy consumption:

- Air tightness is a prerequisite for low energy consumption.
- Related to a situation in which the inhabitants do not use the supply provisions, demand control results in comparable energy consumption
- Depending on the actual use of provisions by inhabitants with demand control reasonable energy savings can be reached.

REFERENCES

Cornelissen H.J.M., de Gids W.F. Opbouw van het gegevens bestand Luchtdoorlatendheid van woningen.
94-BBI-R1762
Delft 1994

De Gids W.F., Phaff J.C, Kornaat W, Rekenstudie naar de consequenties van minimaal gebruik van ramen en ventilatievoorzieningen. Gevolgen voor toelaatbare emissies uit bouwmaterialen.
B-92-0916
Delft 1992

De Gids W.F. Natural ventilation and energy consumption of dwellings
Report C 482, IMG-TNO.
Delft 1981