National Institute for Public Health
and the Environment
Ministry of Health, Welfare and Sport

Approximating the effect of a building on nearby concentrations

Joost Wesseling, Lan Nguyen, RIVM

Version 1.0, 15 February 2015 (including comments by external experts)

Summary

In this paper we describe a simple and relatively robust method to approximate the effect of a building on the dispersion of pollutants emitted from a stack on top of or in the immediate vicinity of the building.

We propose to multiply yearly average concentrations with pre-determined factors, derived from the official Dutch National Dispersion model (NNM) to account for the effects of buildings. The factors used in this approximation can be obtained in several ways: 1. a rough classification of buildings and their associated effects on dispersion, 2. a detailed lookup table for a large number of classes of buildings or 3. 'on the fly' calculations using the Dutch National Dispersion model.

The results from the calculations raise several questions that should be discussed with experts. In the presence of a building the concentrations may increase up to kilometres from the source. In some other cases the concentrations are only halve of the value calculated without a building, both close to the source and at large distances.

Review by external experts

This proposal has been submitted to several external experts for their comments and suggestions: CERC in the UK, VITO in Belgium, TNO and DNV-GL in the Netherlands. On January 15, 2015, a meeting was held in The Hague with these parties as well as representatives from the ministry of Economic Affairs and the ministry of Infrastructure and the Environment. At the end of the meeting several conclusions and recommendations were formulated by the RIVM and agreed upon by all parties. These are therefore also the recommendations from RIVM to the ministry of Economic Affairs and the ministry of Infrastructure and the Environment:

1. Preferred way of including the effect of buildings: Extract a software 'building module' to be included in AERIUS, i.e. the source code of the NNM building module. Fall-back option: Use option 3 of the RIVM proposal: "NNM pre-calculation".

2. Using a cut-off distance to take building effects into account (or not) should take the concentration levels into account, not only distance.

3. The sensitivity of the modelling of the building influence on concentrations and deposition should be investigated.

Section 9 discusses the comments and recommendations, as well as answers from the external experts to several questions, in more detail.

1. Introduction

The Dutch National Dispersion Model (Dutch: NNM) is the official Dutch model for calculations regarding point and area sources (industrial and agricultural sources). The NNM calculates dispersion of emissions from stacks, on an hourly basis, using hourly estimates for meteorological circumstances and emission characteristics (Erbrink, 1995, Ham, 1997 and 1998, EIONET). A general drawback of performing hourly calculations is the time required, which can be substantial for larger numbers of sources and receptors. The NNM is used extensively to assess air quality and check compliance with European and Dutch legal limit values.

A building can have a significant influence on the dispersion of emissions. The NNM accounts for this influence of buildings by adjusting the dispersion calculation in each hour, depending on the specific meteorological circumstances, emission characteristics and building dimensions and orientation. There have been, and still are, discussions in the Netherlands regarding the general validity of the buildings module of the NNM. A previous study on the Dutch building effect module (Potma *et al*, 2012) compared the results of the NNM (+ building module) to that of other models, some field measurements and the results of wind tunnel experiments. The results of calculations with the NNM and ADMS for a relatively low building, taken from Potma, are presented in Appendix 1. Overall, the study concluded that the results of the NNM are comparable to those of other models. According to the report, the NNM performed reasonably well when compared to the results of field measurements near relatively low (height < 7 meter) agriculture sources. Comparing the NNM to the Thompson wind tunnel data showed that several aspects of the building module need improvements. The aim of the present paper is not primarily to define an alternative to the building effects calculated by the NNM, but only an approximation. However, the calculations performed for the present study do raise several questions that need to be addressed.

Recently, the Dutch government has started developing an air quality management system (AERIUS) designed for calculating deposition. It calculates the level of nitrogen deposition in so-called ‘Natura 2000’ areas[1], caused by projects and development plans. In the near future AERIUS aims not only to calculate deposition, which requires the concentrations first, but also to assess concentration levels with regard to European and Dutch legislation. A short description of AERIUS is provided in Appendix 2. As the monitor function of AERIUS is used to calculate the combined effects of many (thousands) of nitrogen-emitting sources (agriculture, industry, traffic and transport), a fast calculation scheme is essential. Therefore, the present version of AERIUS is built around a calculation module based on the Dutch OPS model[2] (Jaarsveld 1993, 1995, 2004). The OPS model is fast and robust but only produces yearly average concentrations. The hourly methods used in the NNM to account for buildings can, therefore, not be implemented in OPS.

Several methods have been suggested to approximate the effect of buildings calculated by the NNM to yearly average concentrations. As the present model approach to the effect of buildings is described in Dutch law, this approach has to be reproduced by new approximate methods. A simple approximation suggested by the RIVM is to multiply yearly average concentrations with pre-determined factors (derived from the official NNM) to account for the effects of buildings.

The approximation described here will primarily be used in the calculations performed by AERIUS on agriculture sources. Effects of the types of buildings commonly found as part of these sources should therefore fall within the application range of the approximation. The uncertainty of concentrations calculated using the NNM around buildings is assumed to be significant. Differences in concentrations around buildings obtained using the full NNM (including hourly effects of the building) and the NNM with the approximation should not exceed an estimated 20%.

---

[1] See http://ec.europa.eu/environment/nature/natura2000/

[2] When discussing individual sources “concentration(s)” will mean “concentration contribution(s)”

2. Testset

In the framework of the Dutch National Air Quality Cooperation Programme (NSL) the PM10 concentrations around the largest agriculture sources in the Netherlands are calculated on a yearly basis. The results become part of the yearly report on air quality provided to the European Commission. All calculations are performed using the NNM. Local authorities provide all inputs for the calculations. The agriculture sources in the NSL are assumed to be the largest emitters in their sector. We have therefore assumed the configurations of these sources to be representative for the buildings for which the approximation must be valid.

The classification of the inputs in the NSL data set was based on the size and height of the buildings, the height, area and exhaust speed of the stacks on the buildings (see table 1). Of the 2552 agriculture sources 2441 buildings have a height between 2 and 8 meter. Only 92 buildings were higher. We have therefore assumed an average building height of 5 meter. Buildings with a height less than or equal to 1.5 meter are ignored by the model. Orientation of the building is set at 90 degrees. The configurations are applied on a fictive farm in the province “Noord-Brabant”, where many of the farms are located. When the height of the stack is higher than the height of the building, the stack is set in the middle of the building; for stack lower than building (a ‘side-exhaust’), the stack is set at 0.5 m outside the building, at the southern side. When a low exhaust is located *within* the building, the model does not function properly.

The buildings in the test set were classified on the basis of the total height of the stack (H), the exit speed at the stack (U), the diameter of the stack (D), the ratio of the length and width of the building (R) and the length (L). Every configuration was labelled with a code consisting of five digits: HUDRL. Not every possible combination of HUDRL contained actual buildings. The selection resulted in 310 classes, shown in Table 1.

Table 1 Definition of classes used to classify building configurations.

CODE	**Class**	**Class average**
	Height stack [m]	
H = 0	0-1	0.5
1	1-3	2
2	3-5	4
3	5-7	6
4	7-9	8
5	9-11	10
6	11-13	12
	Exit speed [m/s]	
U = 1	U <1.0	0.5
2	U 1.0-2.5	1.75
3	U 2.5-5.0	3.75
4	U >5.0	6
	Diameter [m]	
D = 1	D < 1.0	0.5
2	D 1.0-2.5	1.75
3	D 2.5-4.0	3.25
4	D >4.0	5
	Ratio R (W/L)	
R = 1	R <0.25	0.15
2	R 0.25-0.5	0.375
3	R >0.5	0.6
	Length [m]	
L = 1	L<50	30
2	L 50-100	75
3	L>100	105

One stack in the test set has a height of 65m. For this case a separate calculation was performed with the actual stack height. The calculations were performed using a terrain roughness of 10 cm. In practice, the local roughness's around agriculture sources varies around this value. All classes in our test set and the number of buildings falling into each class are shown in Appendix 3.

Figure 1 shows the distribution over the classes of the 2192 buildings for which calculations were possible. Most source diameters fall into class 1, whereas most building lengths are in class 2. The exhaust speeds of the sources fall almost exclusively into classes 1 and 3. Both the source height and the ratio of the building dimension are reasonably distributed in the classes 1, 2 and 3.

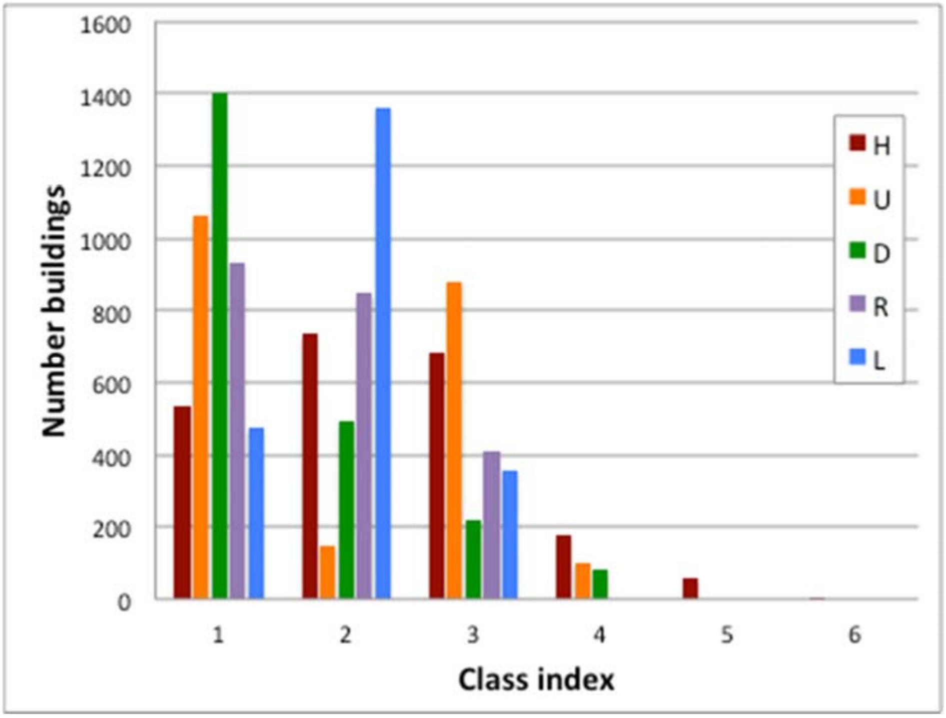

Figure 1 The number of actual buildings in the test set in each of the classes Height, Exit speed, Diameter, Ratio and Length.

Roughly 50% of the buildings fall in 18 classes and some 86% of all buildings fall in one of hundred classes. Almost 180 of the 257 classes contain only 1 – 5 buildings.

<u>Note</u>: We are aware that not all possible combinations of building- and emission characteristics and boundary conditions may be included in the test set used in this analysis. As the necessary calculations have been automated using MATLAB it is easy to extend the test set to cover every possible combination needed for use in AERIUS. Should the approximation described in this paper be incorporated in AERIUS, we will ensure all relevant buildings and conditions are covered.

3. Calculations and analysis

For all 310 sets of sources and buildings, the PM10 concentrations were calculated on a polar grid consisting of 12 wind directions and 26 distances, up to 3 km from the source. The calculations were performed using the implementation for the NNM (ISL3a, version 2014) provided by the ministry of Infrastructure and the Environment. Creation of the input and part of the analysis were in part performed using MATLAB.

For all classes in our test set, two calculations were performed for the year 2013 using the NNM: one including the effect of the building in the configuration and one without. Next, the ratios of these concentrations (with / without building) were calculated for all points in the polar grid. Subsequently, we plotted the ratios as a function of the distance from the source for all configurations and all points and looked for structures in this data set. An example, for the class H=2, U=4, D=1, R=2 and L=2, is presented in figure 2. The ratios of the concentrations calculated with and without taking the influence of the building into account are shown in the figure. The average concentrations of all wind directions (red lines) are also shown as a function of distance to the source. The concentrations decrease rapidly with increasing distance.

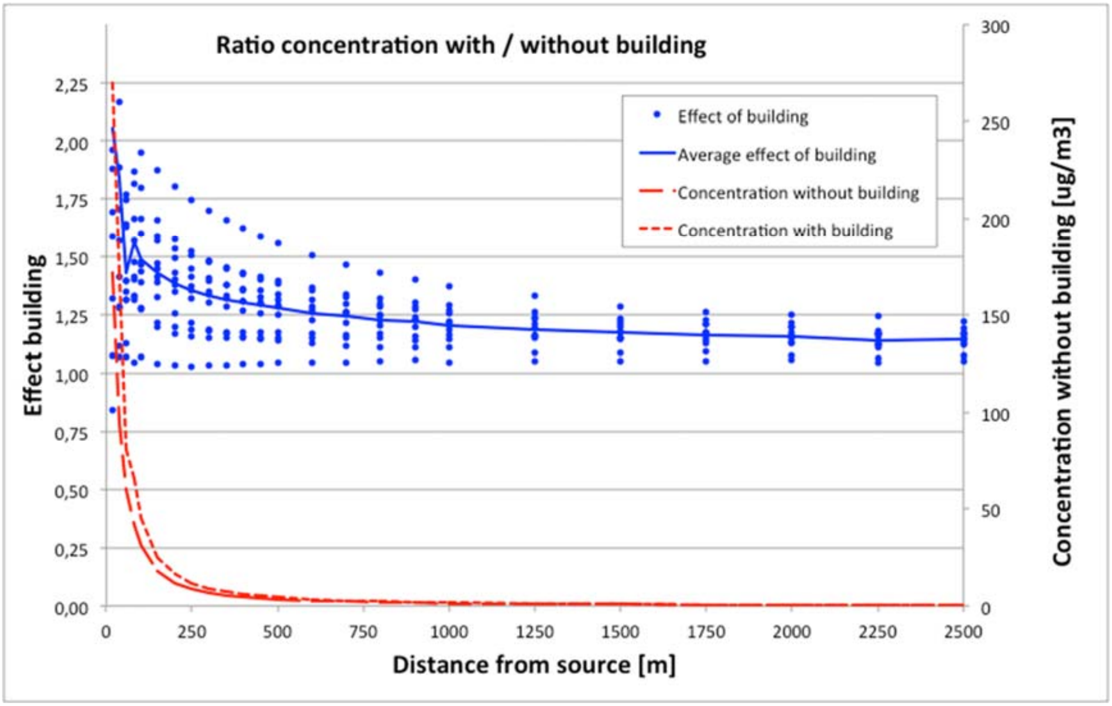

Figure 2 The red lines are the concentrations calculated with/without effect of the building. The blue dots are the ratios of the concentrations in all wind directions calculated with and without the effect of the building. The solid blue is the average effect of the building.

The blue dots are the ratios of the concentrations in all wind directions, calculated with and without the effect of the building. There are twelve blue dots (wind directions) at every distance. On average, there is a significant effect of the building at smaller distances, i.e. concentrations are increased by 50% at a distance of 100 meters from the source. The effect of the building on the concentrations decreases with increasing distance. For the larger distances the effect of the building converges[3] to 15%. It should be noted, at 2 km from the source the absolute concentrations are quite small: 0.63 and 0.55 µg/m3.

Ratios of concentrations have been obtained for all 257 classes in our present test set; the results are presented in Figure 3.

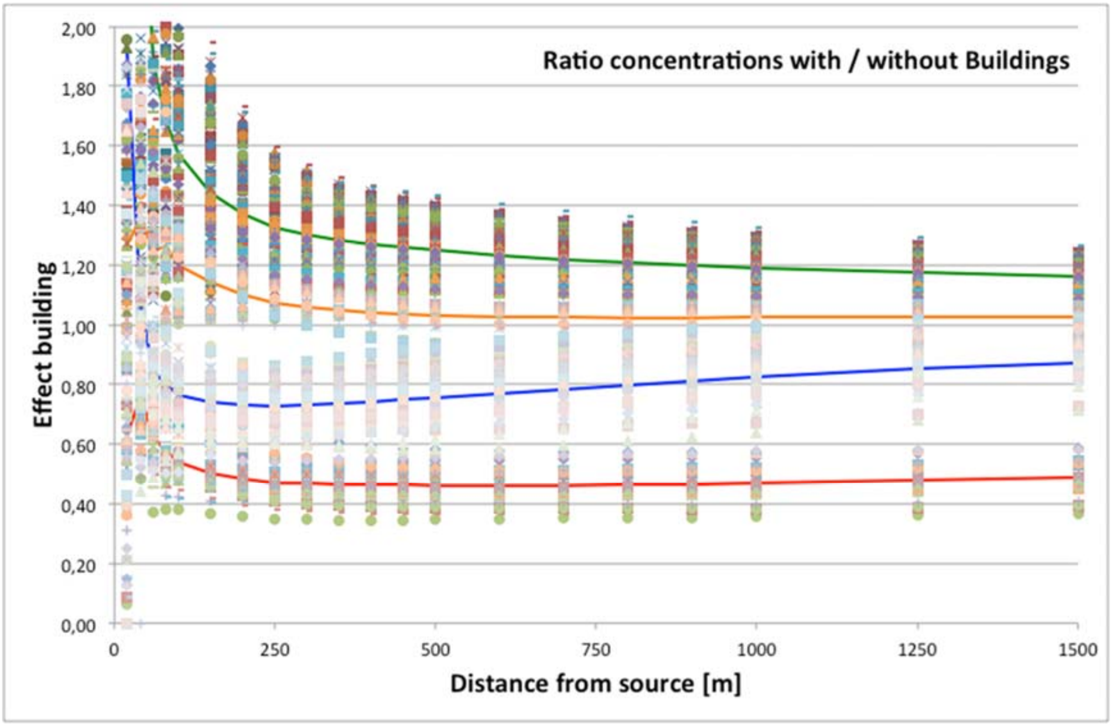

Figure 3 *Ratio's of concentrations with/without effect of building. The solid lines are not fits to the data, but only to guide the eye.*

Several sets of results appear in Figure 2: One set, labelled with the red line, show effects of the building that quickly drop to a value of roughly 0.5 and remains almost constant with distance. A second set, labelled with the blue line, also drops but quickly increases again. However, it stays below unity, The third set, labelled with the orange line starts with a positive effect and then quickly drops to values just above unity. Finally, there is a set where the effects start positive (increased concentrations) and remain substantial.

---

[3] A known feature of the building module in the NNM is an increase in concentration levels at large distances from the source, even at 2-3 kilometres.

Every point in Figure 2 represents the effect of the building at the specified distance, averaged over twelve wind directions. As both the shape of the building and the orientation can vary, the effect of the building will also vary with the wind direction. It is therefore important to verify how the effects of the building vary with the wind directions. Presented in Figure 4 are the standard deviations of the effects in twelve directions, divided by the average effect, plotted as a function of the average effect of the building at that distance. The results are presented for all classes and distances of 150, 500 and 1000 meter from the source.

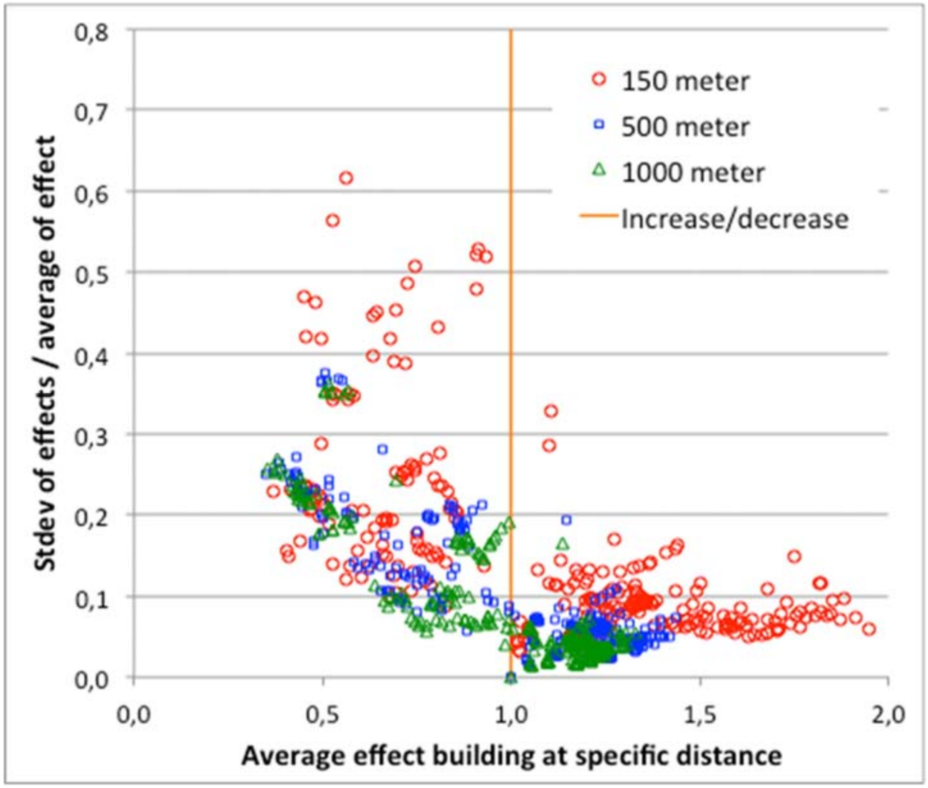

Figure 4 *Standard deviations of the effects of buildings in twelve directions, divided by the average effect, plotted as a function of the average effect of the building. The vertical line separates positive effects (increased concentrations) of buildings, right of the line from negative effects (decreased concentrations) of buildings, left of the line.*

For buildings with an average effect around or larger than 1.0, i.e. the concentrations are similar or higher when the building is present, most of the standard deviations are smaller than 10% of the average effect. So, there is some variation in effect over the wind directions, but not much. For buildings with an average effect well below 1.0, i.e. the concentrations are lower when the building is present, the standard deviation can be larger. However, only in a few cases is the sum of the standard deviation and the average value larger than 1.0. Therefore, ignoring the effect of the buildings with an average effect not exceeding 1.0 seems a robust approach, even taking into account the variations with wind directions.

The effects of the sub set of buildings that lead to increased concentrations are plotted in figure 5. These are the configurations for which using the official building module results in concentrations that are systematically higher than without a building.

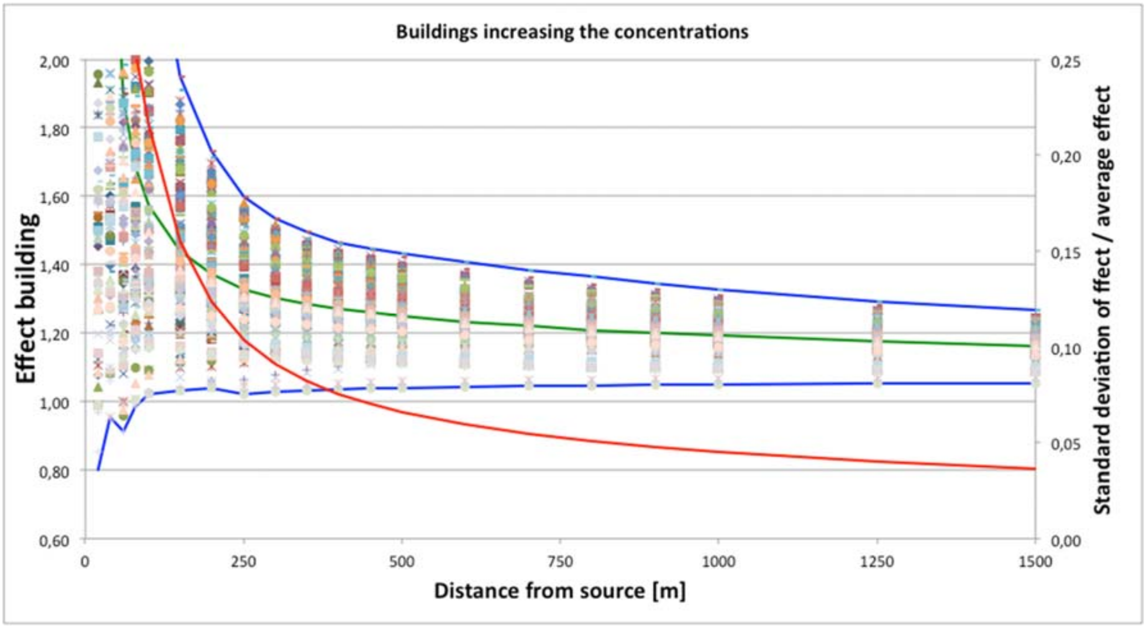

Figure 5 *Average effects of, minimum (blue), maximum (blue) and average (green) effects. The standard deviation of the effects, divided by the average effect is plotted in red.*

The average, median, minimum and maximum effects of the buildings as a function of the distance to the source, are listed in table 2. Also listed are the standard deviation of the effects for each distance from the source and the ratio of the standard deviation and the average effect.

Table 2 *Effect of building configurations on concentrations.*

Distance	**Average**	**Median**	**Minimum**	**Maximum**	**StDev**	**StDev/Avg**
20	6.92	2.17	0.80	40.21	9.06	1.31
40	2.65	1.89	0.95	10.03	1.74	0.66
80	1.69	1.61	0.99	3.21	0.43	0.25
150	1.44	1.38	1.03	1.95	0.22	0.15
250	1.33	1.31	1.02	1.60	0.14	0.10
500	1.25	1.25	1.04	1.43	0.08	0.07
1000	1.19	1.19	1.05	1.33	0.05	0.04
1500	1.16	1.16	1.05	1.27	0.04	0.04
2000	1.15	1.14	1.05	1.22	0.03	0.03
2500	1.13	1.13	1.06	1.20	0.03	0.03
3000	1.13	1.12	1.06	1.18	0.03	0.02

Close to the source, at ranges up to 80 meters, the effects of the buildings are large, with large standard deviations. At larger distances, from 150 meters, the standard deviations become relatively small.

Note: We are aware that the effects of buildings haven only been studied using the meteorology for 2013. We do not expect the effect to vary strongly from year to the. This has to be verified.

4. General methodology and implementation

4.1 Rule of thumb

As mentioned before, several distinct sets of results appear in figure 1. These sets are confirmed by additional PCA (Principal Components analysis) that was performed but is not reported. We can identify two main categories:

Category 1: concentrations with building lower or roughly equal
There are two distinct sub sets of results where the ratio of the concentration with / without the building is below unity, marked with the red and blue lines in the figure. The set with the red line converges to values around 0.5, even at larger distances from the source. The set with the blue line drops quickly below unity and the increases again with distance. The net effect of the building remains negative.

We label these groups Category 1A. This category contains the configurations for which using the official building module results in concentrations that are systematically lower than obtained without including the building. Ignoring the effect of the building therefore leads to an overestimation of the concentrations.

Although not very clear to see, there also is a set of configurations where the effect of the building is positive at short distances but after roughly 200 meter the effect is already below 15-20% and it further decreases with larger distances from the source. This set is labelled using the orange line in the figure. We label this group Category 1B. A practical maximum difference of 15% effect at 150 meter from the source is used to define this set. Ignoring the effect of the building therefore may lead to a small (less than 15%) overestimation of the concentrations. We have already shown that variations with wind directions are relatively small. Therefore, ignoring the effect of the buildings in Category 1 seems a robust approach.

Category 2: increased concentrations due to building
Category 2 contains the configurations for which using the official building module results in concentrations that are systematically higher than obtained without including the building. Ignoring the effect of the building therefore leads to an underestimation of the concentrations. In practice, Category 2 encompasses (almost) all building configurations not included in the above description for category 1.

Category unknown
The implementation of the NNM that was used for the calculations, ISL3a (version 2014) performs a number of checks on the input. Some emission characteristics are considered invalid input if no building is present. As a result we could not always deduce the effect of the building on the dispersion from one calculation

with and one without the building configuration. This happened in roughly 14% of all cases. The effect of the building on the concentrations could not be assessed.

Issue to be discussed

In several cases the NNM cannot calculate the concentrations for situations with and without a building. As a result the effect cannot be determined.

The simplest approximation, for a given configuration, is to estimate if it falls into Category 1 or 2 and then use the general (average) building effect that is appropriate for that specific category. In appendix 4 several plots are presented, showing the relation between the class indexes and the building effects. None of the class indexes stack (H), exit speed at the stack (U), diameter of the stack (D), ratio of the length and width of the building (R) and the length (L) can be used to classify a building as either ‘Category 1’ or ‘Category 2’. However, analysis shows that buildings can be characterized as follows:

Proposed classification for low buildings

Category 1 contains buildings with:
High exit speed from stack in combination with a large stack diameter,
i.e. $(U \geq 3 \text{ AND } D \geq 2)$ OR $(U \geq 2 \text{ AND } D \geq 3)$
OR
Low stack height, low exit speed from stack and small diameter,
i.e. H, U, D all class 1

Category 2 contains all other buildings.

The results of the applying this classification to our test set have been compared with those of the explicit calculations.

- In our test set, 108 out of 257 configurations (42%) fall within one of the above criteria for Category 1 and indeed have no significant or a negative effect on the concentration.
- In 3 out of 257 cases (1%) a configuration was classified ‘Category 1’ while the effect of the building was larger than 1.10 (i.e. ‘Category 2’), so the criteria resulted in the wrong classification. These cases fall in the “High exit speed and large diameter” criteria.
- The “Low stack height, exit speed and small diameter” applied to 9 out of the above 108 configurations. In all these cases the effect of the building was marginally larger than 1.0, with a maximum of 1.02.
- The remaining 57% per cent of the configurations in the test set fall into category 2, and belong there.

For buildings that fall into the above categories 1 and 2 we propose the following approximation for the effect of the building:

Proposed effects of building for low buildings

For Category 1 a robust and conservative approach to approximate the effect of the building is to simply ignore the effect of the building.

For Category 2 a robust and simple approach is to multiply the calculated yearly average concentration with the appropriate factor from table 2.

Using a rule of thumb to classify building configurations does have disadvantages, as some configurations cannot be classified easily in one of the available categories. The classification is not perfect, as shown above. Furthermore, the actual differences between some configurations are smaller than the differences between their categories.

4.2 Use of classes and a look-up table

An alternative to the rule of thumb, described above, is to use all underlying information. The present calculations have resulted in a large table containing the effects of a building for 257 classes of configurations. Each entry in the table is labelled with an identifier specifying the class of buildings it represents.

It is relative straightforward to use the table with all calculated effects of the buildings in the AERIUS calculation module as a look-up table for the building effects. Given an agriculture source with a building, table 1 in this report can be used to determine which class the source and building belong to. Subsequently, the associated building effects are taken from the look-up table and used in the AERIUS calculation. With this procedure it is not necessary to estimate which of the categories a building belongs to. Furthermore, it is easy to use the pre-calculated effects of the building for all wind directions, as these are also available in the table.

4.3 Full automation

The calculations performed by the AERIUS system are highly automated. It should, therefore, be relatively simple to pre-process the input for an agriculture source by explicitly performing two calculations (with and without building) using the implementation of the NNM: ISL3a. Each year RIVM obtains a special version of this model in order to perform the yearly NSL calculations. This version can be used in batch mode, without the need for a user interface. This version of ISL3a, or an even more specialized version, can also be used in AERIUS.

In such an automated approach it is furthermore easy to store the effect of the building for a number of wind directions, instead of just one ratio for all directions. The pre-processing has to be performed only once a year for a specific source as the meteorology has some influence on the effect of buildings.

The important advantage of this automated pre-processing is that it exactly reproduces the effect of any specific building calculated by the NNM. There is no need to select a specific class of building. There is, however a set of configurations for which a calculation with / without a building is not possible. A work-around for these has to be developed. The present analysis does not provide a solution for these situations.

5. Questions regarding the building effect in the NNM

The calculations and analyses presented in the preceding sections lead to several questions regarding the calculated concentrations.

5.1 Concentrations at larger distances

As mentioned before, a known feature of the building module in the NNM is an increase in concentration levels at large distances from the source, even at 2-3 kilometres. In (Potma, 2012) the increase was shown to follow from definitions in the NNM, in combination with the assumed influence of a building on the height of the plume. I.e. it is not a 'bug', but a feature. These increased concentrations (+19% at 1 km) are observed for all cases in our 'Category 2'.

Calculations performed by Potma using both the NNM and ADMS resulted in consistently higher NNM concentrations at large distances. At 1 km the NNM results were on average 17% higher than those of ADMS. The few field measurements available also do not seem to suggest increased concentrations beyond several hundreds of meters from the source, although there is a limited amount of data available.

Issue to be discussed

A question, to be discussed with (international) experts, is "How realistic (i.e. in the real world) are the (19%) increased concentrations at larger distances in situations with a building?".

In case the observed increase is not considered to be realistic, the average effect of a building presented in Table 2 might, for example, be adjusted to show no effect any more at distances of 1 kilometre and more from the source. The average effect, adjusted to yield 1.0 at 1 kilometre from the source and beyond, is shown in Figure 6. It is compared to the average effect taken from Table 2.

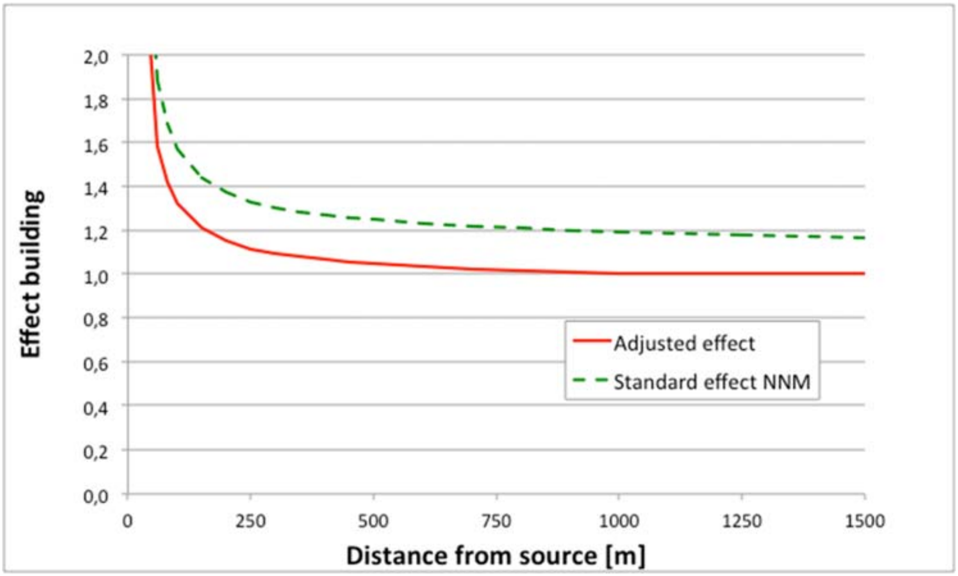

Figure 6 Average positive effect of building, standard and adjusted to yield an effect of 1.0 at 1 kilometre from the source.

5.2 Low concentrations with buildings

In quite many cases the configurations with $U \geq 3$ AND $D \geq 3$ yield a building effect well below unity, as low as 0.5. Often the effect remains this low, also at larger distances up to kilometres. The physics behind this effect is not fully clear. Even though the cases with strongly decreased concentrations may not be relevant for the present analysis, the underlying reasons may indicate issues with the building module of the NNM.

Issue to be discussed

An issue to be investigated and discussed with (international) experts, is “How realistic are the strongly decreased concentrations (up to 50%) at larger distances?”.

6. Summary

In this paper we describe how yearly average concentrations around low buildings can be multiplied with pre-determined factors, derived from the official Dutch National Dispersion model, to account for the effect of buildings.

Three practical implementations were described:

1. A rough classification of buildings into two classes ‘1: No effect or negative effect of building on concentrations’ and ‘2: positive effect of building on concentrations’. A reasonably robust rule of thumb for classifying configurations was described, in only 1% of 257 cases did the classification fail. Estimates of the effects on dispersion were presented.

2. Use of a detailed lookup table for a large number of classes of buildings. This is the table used to construct the proposal described above.

3. ‘On the fly’ calculations using the Dutch National Dispersion model. Using this approach, for every configuration the specific effects of the building are calculated in a pre-processing step.

There are several cases where the concentrations in the situation without a building cannot be calculated using the NNM. For these situations a solution still has to be found.

The available data raises several questions that should be discussed with (international) experts:

- Relatively high concentrations sometimes occur at larger distances when a building is present. Depending on expert opinion this behaviour at large distances should be investigated. Also, an adjusted effect at larger distance may be considered.

- In several cases building effects are well below unity, effects as low as 0.5 are observed. The physics behind this effect is not fully clear.

7. Review and comments by external experts

This proposal has been submitted to several external experts for their comments and suggestions: CERC in the UK, VITO in Belgium, TNO and DNV-GL in the Netherlands. On January 15, 2015, a meeting was held in The Hague with these parties as well as representatives from the ministry of Economic Affairs (Diederik Metz) and the ministry of Infrastructure and the Environment (Aad Bezemer). The following external experts were present: Christina Hood and David Carruthers (CERC), Wouter Lefebvre (VITO), Sjoerd van Ratingen (TNO) and Hans Erbrink (DNV-GL).

All parties provided comments on the proposal of the RIVM before the meeting took place. CERC included several sensitivity tests into their comments, showing the importance of heat content and building orientation. Based on the comments on the proposal provided by the experts, RIVM presented a list of comments and suggestions made by practically all parties:

- The test set for the rule of thumb is not exhaustive, more cases can/should be included, especially covering meteo, height building/stack, configuration of the building, orientation of the building, location of the building, heat, year, …

- More classes are easy to use with a lookup table.

- There should be a better definition / limit of the scope of the discussed rule of thumb.

All parties agreed with these remarks/comments. It should be noted that a full and exhaustive description of all possible cases was not the aim of the present proposal, as remarked at the end of section 2.

Regarding the questions on the relative building effects at larger distances, both significant increases as well as decreased concentrations, all parties agreed that these effect can indeed occur. However, especially at distances of kilometres away from small source the absolute effects will be small, possibly insignificant.

Several possible alternative ‘rules of thumb’ to take building effects into account (methods D1 and H1) were provided by CERC in their report. They also showed the effect of these rules of thumb compared to the full incorporation of building effects into ADMS, as well as AERMOD. Combined with the sensitivity test for heat content and orientation of the building, the results of CERC show the substantial uncertainty involved in the effect of buildings on concentration levels. All details are provided in the report of CERC.

At the end of the meeting the following conclusions and recommendations were formulated by the RIVM and agreed upon by all parties. These are therefore also the recommendations from RIVM to the ministry of Economic Affairs and the ministry of Infrastructure and the Environment:

1. Preferred way of including the effect of buildings: Extract a software building module to be included in AERIUS, i.e. the source code of the NNM building module.

   Fall-back option: Using option 3 of the RIVM proposal: "NNM pre-calculation".

2. Using a cut-off distance to take building effects into account (or not) should take the concentration levels into account, not only distance.

3. Sensitivity of the modelling:
   - Heat content has non-trivial influence and should therefore be included in the calculation of the building effect.
   - The effect of a building on the turbulence and therefore also on the deposition speed should be investigated.
   - The effect of concentration level on deposition speed may be important and should be investigated.

<u>Comments were provided in the following reports/notes:</u>
CERC: "Assessment of the validity and usability of an approximation of the effect of a building on nearby concentration levels", Final Report, Prepared for Ministerie van Economische Zaken, 16th January 2015.

VITO: Comments on the RIVM-report 'Approximating the effect of a building on nearby concentrations', Study accomplished under the authority of 'Ministerie Economische Zaken, Nederland' 2014/RMA/R/205, January 2015.

TNO: Final comments: Approximating the effect of a building on nearby concentrations, 22 January 2015.

DNV-GL: Comments to "Approximating the effect of a building on nearby concentrations", Version 0.90, 20 October 2014.

References

EIONET, http://pandora.meng.auth.gr/mds/showlong.php?id=88

Erbrink, J.J., 1995, “Turbulent diffusion from tall stacks”, Ph.D. thesis, Free University of Amsterdam.

Jaarsveld J.A. van, (1995). Modelling the atmospheric behaviour of pollutants. Proefschrift Universiteit Utrecht; RIVM rapport nr. 722501005.

Jaarsveld J.A. van, (2004). The Operational Priority Substances Model. Description and validation of OPS-Pro 4.1. RIVM rapport nr. 500045001. (PDF, 2029Kb)

Jaarsveld J.A. van en F.A.A.M de Leeuw, (1993). OPS: An operational atmospheric transport model for priority substances. Environmental software 8, 91-100.

Ham, J. van, 1997, Journal Article “Revision of the Netherlands National Model for short range dispersion of air pollutants”, International Journal of Environment and Pollution, Volume 8, Number 3–6/1997, 771-777

Ham, J. van, 1998, Project group Revision National Model, The New National Model, research report of the project group Revision National Model (in Dutch), TNO Environment, Energy and Process Innovation, Apeldoorn, the Netherlands.

OPS model web page:
http://www.rivm.nl/Onderwerpen/O/Operationele_Prioritaire_Stoffen_model/Modelbeschrijving/Referenties

Potma C. (FlowMotion), S. van den Akker (Peutz), S. van Ratinger (TNO), J.J. Erbrink, E. Kokmeijer en L. Verhees (DNV KEMA), “Re-calibration building module: an analysis, validation and suggestions for improvement”, 74101268-CES/ECS 12-7432, 2012 (in Dutch).

Appendix 1 Calculations using the NNM and ADMS

A previous study on the Dutch building effect module (Potma, 2012) compared the results of the NNM + building module to that of ADMS (version 2012). The result, for a set of receptors located east-west of the building is presented below.

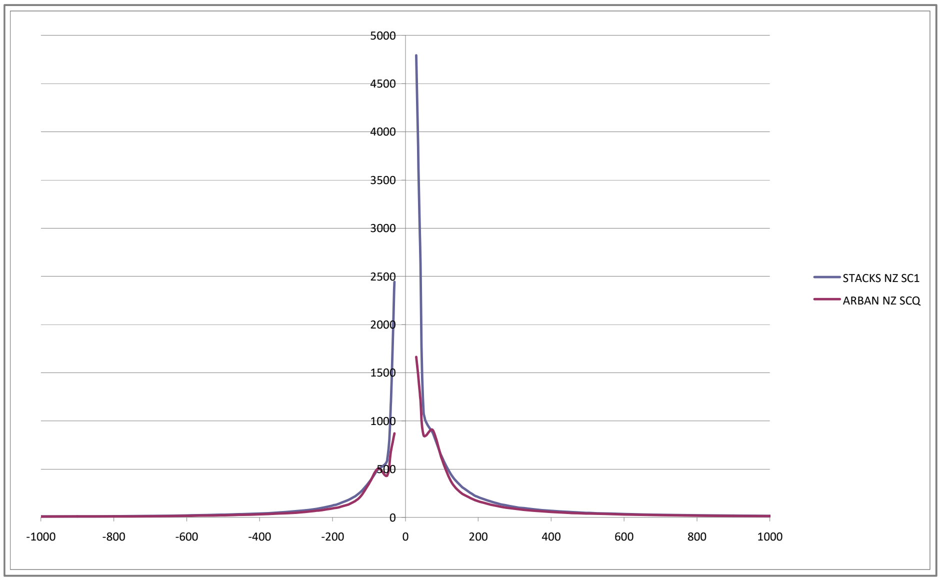

Figure A1-1 Comparison of ADMS and NNM results

The stack is 10 meter high, 50 meter long and 20 meter wide. The height of the building is 8 meter, with the exhaust 2 meter above the roof. There is no heat content of the plume. Both models agree quite well. A similar result was obtained for receptors oriented north-west, presented below.

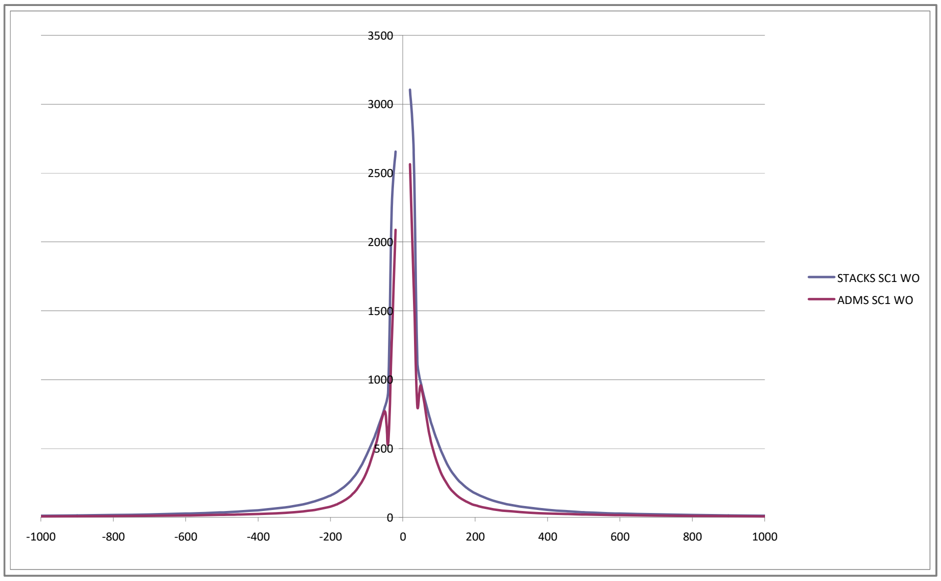

Figure A1-2 Comparison of ADMS and NNM results

For higher buildings and substantial heat content of the plume the differences between the results of both models increased substantially. In all cases the concentrations calculated with the NNM at 1 km from the source were higher than those calculated using ADMS. For the 8 meter high building the ratio of concentrations calculated at 1 km using the NNM were roughly 17% higher than obtained using ADMS.

Appendix 2 About AERIUS[4]

The Integrated Approach to Nitrogen (PAS) is the Dutch policy for coping with the issues around nitrogen. The PAS will ensure that the objectives of European nature policy are being achieved, while creating the necessary room for economic development.

AERIUS, the calculation tool of the PAS

The AERIUS calculation tool is one of the cornerstones of the Integrated Approach to Nitrogen (PAS). It calculates the level of nitrogen deposition in Natura 2000 areas, caused by projects and development plans. AERIUS supports the issuing of permits for economic activities that involve the emission of nitrogen, and monitors whether the total nitrogen burden continues to decline. In addition, AERIUS also facilitates spatial planning in relation to nitrogen.

For all areas and sectors

AERIUS may be used for calculations for all nitrogen-sensitive Natura 2000 areas and all nitrogen-emitting sectors (agriculture, industry, and traffic & transport). In this way, AERIUS is in keeping with the area- and sector-exceeding character of the PAS.

Applications

AERIUS calculates nitrogen deposition levels of projects and plans related to Natura 2000 areas. It can be applied to:

- The issuing of permits under the Dutch Nature Conservation Act
- Spatial planning
- Monitoring of the PAS

Room for development

The Integrated Approach to Nitrogen (PAS) distinguishes two ways for realising the Natura 2000 nature conservation objectives:

- Achieving a continued reduction in nitrogen deposition through the implementation of measures at the source.
- Implementing restoration strategies for nature sensitive to nitrogen deposition. Restoration strategies consist of a set of ecological restoration measures to improve nature quality.

---

[4] Source: http://www.aerius.nl/en/about-aerius and links from that web page.

According to the PAS part of the reduction may be used for new or expanded economic activity. This allowed amount of development is referred to here as ‘room for development’. In this way, a continued reduction in nitrogen deposition is ensured, while leaving room for much needed economic development and, therefore, also for investments in cleaner production technology. Thus, a balanced approach is created with economic activity remaining possible on the condition that nature objectives will be achieved.

How much room for development is there?

For each Natura 2000 area, in a so-called area analysis it is determined how much, if any, room for development would be available.

Appendix 3 Number of buildings within classes

Class	Number buildings	Height Source	U exhaust	Diameter	Ratio	Length
33112	111	H 5-7	U 2.5-5.0	D < 1.0	R < 0.25	L 50-100
21112	100	H 3-5	U < 1.0	D < 1.0	R < 0.25	L 50-100
23112	81	H 3-5	U 2.5-5.0	D < 1.0	R < 0.25	L 50-100
11131	78	H 1-3	U < 1.0	D < 1.0	R > 0.5	L < 50
11112	72	H 1-3	U < 1.0	D < 1.0	R < 0.25	L 50-100
11212	65	H 1-3	U < 1.0	D 1.0-2.5	R < 0.25	L 50-100
33122	64	H 5-7	U 2.5-5.0	D < 1.0	R 0.25-0.5	L 50-100
11121	60	H 1-3	U < 1.0	D < 1.0	R 0.25-0.5	L < 50
11122	55	H 1-3	U < 1.0	D < 1.0	R 0.25-0.5	L 50-100
21212	52	H 3-5	U < 1.0	D 1.0-2.5	R < 0.25	L 50-100
23122	50	H 3-5	U 2.5-5.0	D < 1.0	R 0.25-0.5	L 50-100
21122	49	H 3-5	U < 1.0	D < 1.0	R 0.25-0.5	L 50-100
31122	47	H 5-7	U < 1.0	D < 1.0	R 0.25-0.5	L 50-100
23121	46	H 3-5	U 2.5-5.0	D < 1.0	R 0.25-0.5	L < 50
31112	44	H 5-7	U < 1.0	D < 1.0	R < 0.25	L 50-100
11222	41	H 1-3	U < 1.0	D 1.0-2.5	R 0.25-0.5	L 50-100
33121	36	H 5-7	U 2.5-5.0	D < 1.0	R 0.25-0.5	L < 50
21121	30	H 3-5	U < 1.0	D < 1.0	R 0.25-0.5	L < 50
33113	27	H 5-7	U 2.5-5.0	D < 1.0	R < 0.25	L > 100
43122	27	H 7-9	U 2.5-5.0	D < 1.0	R 0.25-0.5	L 50-100
21222	23	H 3-5	U < 1.0	D 1.0-2.5	R 0.25-0.5	L 50-100
23131	23	H 3-5	U 2.5-5.0	D < 1.0	R > 0.5	L < 50
31121	23	H 5-7	U < 1.0	D < 1.0	R 0.25-0.5	L < 50
33131	21	H 5-7	U 2.5-5.0	D < 1.0	R > 0.5	L < 50
13213	20	H 1-3	U 2.5-5.0	D 1.0-2.5	R < 0.25	L > 100
23212	19	H 3-5	U 2.5-5.0	D 1.0-2.5	R < 0.25	L 50-100
11132	17	H 1-3	U < 1.0	D < 1.0	R > 0.5	L 50-100
21131	16	H 3-5	U < 1.0	D < 1.0	R > 0.5	L < 50
13121	16	H 1-3	U 2.5-5.0	D < 1.0	R 0.25-0.5	L < 50
23111	16	H 3-5	U 2.5-5.0	D < 1.0	R < 0.25	L < 50
31131	15	H 5-7	U < 1.0	D < 1.0	R > 0.5	L < 50
31113	14	H 5-7	U < 1.0	D < 1.0	R < 0.25	L > 100
33132	14	H 5-7	U 2.5-5.0	D < 1.0	R > 0.5	L 50-100
32322	14	H 5-7	U 1.0-2.5	D 2.5-4.0	R 0.25-0.5	L 50-100
21132	13	H 3-5	U < 1.0	D < 1.0	R > 0.5	L 50-100
23113	13	H 3-5	U 2.5-5.0	D < 1.0	R < 0.25	L > 100
21312	12	H 3-5	U < 1.0	D 2.5-4.0	R < 0.25	L 50-100
43133	12	H 7-9	U 2.5-5.0	D < 1.0	R > 0.5	L > 100
11113	12	H 1-3	U < 1.0	D < 1.0	R < 0.25	L > 100
13212	12	H 1-3	U 2.5-5.0	D 1.0-2.5	R < 0.25	L 50-100
23222	12	H 3-5	U 2.5-5.0	D 1.0-2.5	R 0.25-0.5	L 50-100
24222	12	H 3-5	U > 5.0	D 1.0-2.5	R 0.25-0.5	L 50-100
22322	12	H 3-5	U 1.0-2.5	D 2.5-4.0	R 0.25-0.5	L 50-100
33213	11	H 5-7	U 2.5-5.0	D 1.0-2.5	R < 0.25	L > 100
43333	11	H 7-9	U 2.5-5.0	D 2.5-4.0	R > 0.5	L > 100
11213	10	H 1-3	U < 1.0	D 1.0-2.5	R < 0.25	L > 100
11232	10	H 1-3	U < 1.0	D 1.0-2.5	R > 0.5	L 50-100
32332	10	H 5-7	U 1.0-2.5	D 2.5-4.0	R > 0.5	L 50-100
33222	10	H 5-7	U 2.5-5.0	D 1.0-2.5	R 0.25-0.5	L 50-100
43222	10	H 7-9	U 2.5-5.0	D 1.0-2.5	R 0.25-0.5	L 50-100
43233	10	H 7-9	U 2.5-5.0	D 1.0-2.5	R > 0.5	L > 100
31422	10	H 5-7	U < 1.0	D > 4.0	R 0.25-0.5	L 50-100
43112	9	H 7-9	U 2.5-5.0	D < 1.0	R < 0.25	L 50-100
13112	9	H 1-3	U 2.5-5.0	D < 1.0	R < 0.25	L 50-100
22312	9	H 3-5	U 1.0-2.5	D 2.5-4.0	R < 0.25	L 50-100

23312	9	H 3-5	U 2.5-5.0	D 2.5-4.0	R < 0.25	L 50-100
33212	9	H 5-7	U 2.5-5.0	D 1.0-2.5	R < 0.25	L 50-100
21213	8	H 3-5	U < 1.0	D 1.0-2.5	R < 0.25	L > 100
21113	8	H 3-5	U < 1.0	D < 1.0	R < 0.25	L > 100
23332	8	H 3-5	U 2.5-5.0	D 2.5-4.0	R > 0.5	L 50-100
32312	8	H 5-7	U 1.0-2.5	D 2.5-4.0	R < 0.25	L 50-100
33322	8	H 5-7	U 2.5-5.0	D 2.5-4.0	R 0.25-0.5	L 50-100
31232	7	H 5-7	U < 1.0	D 1.0-2.5	R > 0.5	L 50-100
51131	7	H 9-11	U < 1.0	D < 1.0	R > 0.5	L < 50
31312	7	H 5-7	U < 1.0	D 2.5-4.0	R < 0.25	L 50-100
31322	7	H 5-7	U < 1.0	D 2.5-4.0	R 0.25-0.5	L 50-100
13131	7	H 1-3	U 2.5-5.0	D < 1.0	R > 0.5	L < 50
23213	7	H 3-5	U 2.5-5.0	D 1.0-2.5	R < 0.25	L > 100
32423	7	H 5-7	U 1.0-2.5	D > 4.0	R 0.25-0.5	L > 100
22222	6	H 3-5	U 1.0-2.5	D 1.0-2.5	R 0.25-0.5	L 50-100
31111	6	H 5-7	U < 1.0	D < 1.0	R < 0.25	L < 50
31133	6	H 5-7	U < 1.0	D < 1.0	R > 0.5	L > 100
34112	6	H 5-7	U > 5.0	D < 1.0	R < 0.25	L 50-100
24113	6	H 3-5	U > 5.0	D < 1.0	R < 0.25	L > 100
11221	6	H 1-3	U < 1.0	D 1.0-2.5	R 0.25-0.5	L < 50
13231	6	H 1-3	U 2.5-5.0	D 1.0-2.5	R > 0.5	L < 50
24213	6	H 3-5	U > 5.0	D 1.0-2.5	R < 0.25	L > 100
32422	6	H 5-7	U 1.0-2.5	D > 4.0	R 0.25-0.5	L 50-100
43322	6	H 7-9	U 2.5-5.0	D 2.5-4.0	R 0.25-0.5	L 50-100
43413	6	H 7-9	U 2.5-5.0	D > 4.0	R < 0.25	L > 100
41122	5	H 7-9	U < 1.0	D < 1.0	R 0.25-0.5	L 50-100
41131	5	H 7-9	U < 1.0	D < 1.0	R > 0.5	L < 50
31212	5	H 5-7	U < 1.0	D 1.0-2.5	R < 0.25	L 50-100
53123	5	H 9-11	U 2.5-5.0	D < 1.0	R 0.25-0.5	L > 100
22112	5	H 3-5	U 1.0-2.5	D < 1.0	R < 0.25	L 50-100
21313	5	H 3-5	U < 1.0	D 2.5-4.0	R < 0.25	L > 100
13122	5	H 1-3	U 2.5-5.0	D < 1.0	R 0.25-0.5	L 50-100
11111	5	H 1-3	U < 1.0	D < 1.0	R < 0.25	L < 50
23313	5	H 3-5	U 2.5-5.0	D 2.5-4.0	R < 0.25	L > 100
32432	5	H 5-7	U 1.0-2.5	D > 4.0	R > 0.5	L 50-100
33223	5	H 5-7	U 2.5-5.0	D 1.0-2.5	R 0.25-0.5	L > 100
33312	5	H 5-7	U 2.5-5.0	D 2.5-4.0	R < 0.25	L 50-100
33323	5	H 5-7	U 2.5-5.0	D 2.5-4.0	R 0.25-0.5	L > 100
44223	5	H 7-9	U > 5.0	D 1.0-2.5	R 0.25-0.5	L > 100
44323	5	H 7-9	U > 5.0	D 2.5-4.0	R 0.25-0.5	L > 100
31413	5	H 5-7	U < 1.0	D > 4.0	R < 0.25	L > 100
51422	5	H 9-11	U < 1.0	D > 4.0	R 0.25-0.5	L 50-100
12213	4	H 1-3	U 1.0-2.5	D 1.0-2.5	R < 0.25	L > 100
32212	4	H 5-7	U 1.0-2.5	D 1.0-2.5	R < 0.25	L 50-100
32112	4	H 5-7	U 1.0-2.5	D < 1.0	R < 0.25	L 50-100
32122	4	H 5-7	U 1.0-2.5	D < 1.0	R 0.25-0.5	L 50-100
41132	4	H 7-9	U < 1.0	D < 1.0	R > 0.5	L 50-100
31222	4	H 5-7	U < 1.0	D 1.0-2.5	R 0.25-0.5	L 50-100
34113	4	H 5-7	U > 5.0	D < 1.0	R < 0.25	L > 100
34122	4	H 5-7	U > 5.0	D < 1.0	R 0.25-0.5	L 50-100
53122	4	H 9-11	U 2.5-5.0	D < 1.0	R 0.25-0.5	L 50-100
31332	4	H 5-7	U < 1.0	D 2.5-4.0	R > 0.5	L 50-100
23132	4	H 3-5	U 2.5-5.0	D < 1.0	R > 0.5	L 50-100
21322	4	H 3-5	U < 1.0	D 2.5-4.0	R 0.25-0.5	L 50-100
21233	4	H 3-5	U < 1.0	D 1.0-2.5	R > 0.5	L > 100
11123	4	H 1-3	U < 1.0	D < 1.0	R 0.25-0.5	L > 100
21123	4	H 3-5	U < 1.0	D < 1.0	R 0.25-0.5	L > 100
23322	4	H 3-5	U 2.5-5.0	D 2.5-4.0	R 0.25-0.5	L 50-100
24223	4	H 3-5	U > 5.0	D 1.0-2.5	R 0.25-0.5	L > 100
24313	4	H 3-5	U > 5.0	D 2.5-4.0	R < 0.25	L > 100

33313	4	H 5-7	U 2.5-5.0	D 2.5-4.0	R < 0.25	L > 100
33332	4	H 5-7	U 2.5-5.0	D 2.5-4.0	R > 0.5	L 50-100
63231	4	H 11-13	U 2.5-5.0	D 1.0-2.5	R > 0.5	L < 50
32222	3	H 5-7	U 1.0-2.5	D 1.0-2.5	R 0.25-0.5	L 50-100
51122	3	H 9-11	U < 1.0	D < 1.0	R 0.25-0.5	L 50-100
31213	3	H 5-7	U < 1.0	D 1.0-2.5	R < 0.25	L > 100
33133	3	H 5-7	U 2.5-5.0	D < 1.0	R > 0.5	L > 100
43123	3	H 7-9	U 2.5-5.0	D < 1.0	R 0.25-0.5	L > 100
31231	3	H 5-7	U < 1.0	D 1.0-2.5	R > 0.5	L < 50
24122	3	H 3-5	U > 5.0	D < 1.0	R 0.25-0.5	L 50-100
31323	3	H 5-7	U < 1.0	D 2.5-4.0	R 0.25-0.5	L > 100
43121	3	H 7-9	U 2.5-5.0	D < 1.0	R 0.25-0.5	L < 50
23133	3	H 3-5	U 2.5-5.0	D < 1.0	R > 0.5	L > 100
21133	3	H 3-5	U < 1.0	D < 1.0	R > 0.5	L > 100
12112	3	H 1-3	U 1.0-2.5	D < 1.0	R < 0.25	L 50-100
21111	3	H 3-5	U < 1.0	D < 1.0	R < 0.25	L < 50
13222	3	H 1-3	U 2.5-5.0	D 1.0-2.5	R 0.25-0.5	L 50-100
22313	3	H 3-5	U 1.0-2.5	D 2.5-4.0	R < 0.25	L > 100
23333	3	H 3-5	U 2.5-5.0	D 2.5-4.0	R > 0.5	L > 100
33232	3	H 5-7	U 2.5-5.0	D 1.0-2.5	R > 0.5	L 50-100
33423	3	H 5-7	U 2.5-5.0	D > 4.0	R 0.25-0.5	L > 100
33431	3	H 5-7	U 2.5-5.0	D > 4.0	R > 0.5	L < 50
34232	3	H 5-7	U > 5.0	D 1.0-2.5	R > 0.5	L 50-100
34233	3	H 5-7	U > 5.0	D 1.0-2.5	R > 0.5	L > 100
43312	3	H 7-9	U 2.5-5.0	D 2.5-4.0	R < 0.25	L 50-100
44222	3	H 7-9	U > 5.0	D 1.0-2.5	R 0.25-0.5	L 50-100
54223	3	H 9-11	U > 5.0	D 1.0-2.5	R 0.25-0.5	L > 100
54232	3	H 9-11	U > 5.0	D 1.0-2.5	R > 0.5	L 50-100
31433	3	H 5-7	U < 1.0	D > 4.0	R > 0.5	L > 100
41433	3	H 7-9	U < 1.0	D > 4.0	R > 0.5	L > 100
31412	3	H 5-7	U < 1.0	D > 4.0	R < 0.25	L 50-100
22212	2	H 3-5	U 1.0-2.5	D 1.0-2.5	R < 0.25	L 50-100
42222	2	H 7-9	U 1.0-2.5	D 1.0-2.5	R 0.25-0.5	L 50-100
32231	2	H 5-7	U 1.0-2.5	D 1.0-2.5	R > 0.5	L < 50
31132	2	H 5-7	U < 1.0	D < 1.0	R > 0.5	L 50-100
42112	2	H 7-9	U 1.0-2.5	D < 1.0	R < 0.25	L 50-100
51132	2	H 9-11	U < 1.0	D < 1.0	R > 0.5	L 50-100
33123	2	H 5-7	U 2.5-5.0	D < 1.0	R 0.25-0.5	L > 100
53132	2	H 9-11	U 2.5-5.0	D < 1.0	R > 0.5	L 50-100
22121	2	H 3-5	U 1.0-2.5	D < 1.0	R 0.25-0.5	L < 50
44112	2	H 7-9	U > 5.0	D < 1.0	R < 0.25	L 50-100
11223	2	H 1-3	U < 1.0	D 1.0-2.5	R 0.25-0.5	L > 100
24121	2	H 3-5	U > 5.0	D < 1.0	R 0.25-0.5	L < 50
21331	2	H 3-5	U < 1.0	D 2.5-4.0	R > 0.5	L < 50
21323	2	H 3-5	U < 1.0	D 2.5-4.0	R 0.25-0.5	L > 100
21231	2	H 3-5	U < 1.0	D 1.0-2.5	R > 0.5	L < 50
12131	2	H 1-3	U 1.0-2.5	D < 1.0	R > 0.5	L < 50
13111	2	H 1-3	U 2.5-5.0	D < 1.0	R < 0.25	L < 50
23232	2	H 3-5	U 2.5-5.0	D 1.0-2.5	R > 0.5	L 50-100
23323	2	H 3-5	U 2.5-5.0	D 2.5-4.0	R 0.25-0.5	L > 100
24212	2	H 3-5	U > 5.0	D 1.0-2.5	R < 0.25	L 50-100
24233	2	H 3-5	U > 5.0	D 1.0-2.5	R > 0.5	L > 100
32333	2	H 5-7	U 1.0-2.5	D 2.5-4.0	R > 0.5	L > 100
33233	2	H 5-7	U 2.5-5.0	D 1.0-2.5	R > 0.5	L > 100
33331	2	H 5-7	U 2.5-5.0	D 2.5-4.0	R > 0.5	L < 50
34212	2	H 5-7	U > 5.0	D 1.0-2.5	R < 0.25	L 50-100
34313	2	H 5-7	U > 5.0	D 2.5-4.0	R < 0.25	L > 100
42333	2	H 7-9	U 1.0-2.5	D 2.5-4.0	R > 0.5	L > 100
42412	2	H 7-9	U 1.0-2.5	D > 4.0	R < 0.25	L 50-100
42422	2	H 7-9	U 1.0-2.5	D > 4.0	R 0.25-0.5	L 50-100

43213	2	H 7-9	U 2.5-5.0	D 1.0-2.5	R < 0.25	L > 100
43313	2	H 7-9	U 2.5-5.0	D 2.5-4.0	R < 0.25	L > 100
44322	2	H 7-9	U > 5.0	D 2.5-4.0	R 0.25-0.5	L 50-100
53222	2	H 9-11	U 2.5-5.0	D 1.0-2.5	R 0.25-0.5	L 50-100
53312	2	H 9-11	U 2.5-5.0	D 2.5-4.0	R < 0.25	L 50-100
53322	2	H 9-11	U 2.5-5.0	D 2.5-4.0	R 0.25-0.5	L 50-100
54222	2	H 9-11	U > 5.0	D 1.0-2.5	R 0.25-0.5	L 50-100
31423	2	H 5-7	U < 1.0	D > 4.0	R 0.25-0.5	L > 100
31431	2	H 5-7	U < 1.0	D > 4.0	R > 0.5	L < 50
41422	2	H 7-9	U < 1.0	D > 4.0	R 0.25-0.5	L 50-100
51432	2	H 9-11	U < 1.0	D > 4.0	R > 0.5	L 50-100
31123	1	H 5-7	U < 1.0	D < 1.0	R 0.25-0.5	L > 100
32113	1	H 5-7	U 1.0-2.5	D < 1.0	R < 0.25	L > 100
42113	1	H 7-9	U 1.0-2.5	D < 1.0	R < 0.25	L > 100
42122	1	H 7-9	U 1.0-2.5	D < 1.0	R 0.25-0.5	L 50-100
42132	1	H 7-9	U 1.0-2.5	D < 1.0	R > 0.5	L 50-100
41112	1	H 7-9	U < 1.0	D < 1.0	R < 0.25	L 50-100
41113	1	H 7-9	U < 1.0	D < 1.0	R < 0.25	L > 100
41121	1	H 7-9	U < 1.0	D < 1.0	R 0.25-0.5	L < 50
41123	1	H 7-9	U < 1.0	D < 1.0	R 0.25-0.5	L > 100
41213	1	H 7-9	U < 1.0	D 1.0-2.5	R < 0.25	L > 100
41222	1	H 7-9	U < 1.0	D 1.0-2.5	R 0.25-0.5	L 50-100
41232	1	H 7-9	U < 1.0	D 1.0-2.5	R > 0.5	L 50-100
51213	1	H 9-11	U < 1.0	D 1.0-2.5	R < 0.25	L > 100
51223	1	H 9-11	U < 1.0	D 1.0-2.5	R 0.25-0.5	L > 100
31233	1	H 5-7	U < 1.0	D 1.0-2.5	R > 0.5	L > 100
43113	1	H 7-9	U 2.5-5.0	D < 1.0	R < 0.25	L > 100
43132	1	H 7-9	U 2.5-5.0	D < 1.0	R > 0.5	L 50-100
61122	1	H 11-13	U < 1.0	D < 1.0	R 0.25-0.5	L 50-100
31221	1	H 5-7	U < 1.0	D 1.0-2.5	R 0.25-0.5	L < 50
41312	1	H 7-9	U < 1.0	D 2.5-4.0	R < 0.25	L 50-100
41313	1	H 7-9	U < 1.0	D 2.5-4.0	R < 0.25	L > 100
44122	1	H 7-9	U > 5.0	D < 1.0	R 0.25-0.5	L 50-100
53113	1	H 9-11	U 2.5-5.0	D < 1.0	R < 0.25	L > 100
24131	1	H 3-5	U > 5.0	D < 1.0	R > 0.5	L < 50
53112	1	H 9-11	U 2.5-5.0	D < 1.0	R < 0.25	L 50-100
33111	1	H 5-7	U 2.5-5.0	D < 1.0	R < 0.25	L < 50
31331	1	H 5-7	U < 1.0	D 2.5-4.0	R > 0.5	L < 50
11231	1	H 1-3	U < 1.0	D 1.0-2.5	R > 0.5	L < 50
22213	1	H 3-5	U 1.0-2.5	D 1.0-2.5	R < 0.25	L > 100
42213	1	H 7-9	U 1.0-2.5	D 1.0-2.5	R < 0.25	L > 100
11133	1	H 1-3	U < 1.0	D < 1.0	R > 0.5	L > 100
11211	1	H 1-3	U < 1.0	D 1.0-2.5	R < 0.25	L < 50
12121	1	H 1-3	U 1.0-2.5	D < 1.0	R 0.25-0.5	L < 50
12122	1	H 1-3	U 1.0-2.5	D < 1.0	R 0.25-0.5	L 50-100
12221	1	H 1-3	U 1.0-2.5	D 1.0-2.5	R 0.25-0.5	L < 50
14213	1	H 1-3	U > 5.0	D 1.0-2.5	R < 0.25	L > 100
22321	1	H 3-5	U 1.0-2.5	D 2.5-4.0	R 0.25-0.5	L < 50
22332	1	H 3-5	U 1.0-2.5	D 2.5-4.0	R > 0.5	L 50-100
23231	1	H 3-5	U 2.5-5.0	D 1.0-2.5	R > 0.5	L < 50
24231	1	H 3-5	U > 5.0	D 1.0-2.5	R > 0.5	L < 50
32313	1	H 5-7	U 1.0-2.5	D 2.5-4.0	R < 0.25	L > 100
32321	1	H 5-7	U 1.0-2.5	D 2.5-4.0	R 0.25-0.5	L < 50
32323	1	H 5-7	U 1.0-2.5	D 2.5-4.0	R 0.25-0.5	L > 100
32331	1	H 5-7	U 1.0-2.5	D 2.5-4.0	R > 0.5	L < 50
34213	1	H 5-7	U > 5.0	D 1.0-2.5	R < 0.25	L > 100
42313	1	H 7-9	U 1.0-2.5	D 2.5-4.0	R < 0.25	L > 100
42322	1	H 7-9	U 1.0-2.5	D 2.5-4.0	R 0.25-0.5	L 50-100
43212	1	H 7-9	U 2.5-5.0	D 1.0-2.5	R < 0.25	L 50-100
43232	1	H 7-9	U 2.5-5.0	D 1.0-2.5	R > 0.5	L 50-100

44212	1	H 7-9	U > 5.0	D 1.0-2.5	R < 0.25	L 50-100
44213	1	H 7-9	U > 5.0	D 1.0-2.5	R < 0.25	L > 100
44231	1	H 7-9	U > 5.0	D 1.0-2.5	R > 0.5	L < 50
44232	1	H 7-9	U > 5.0	D 1.0-2.5	R > 0.5	L 50-100
53212	1	H 9-11	U 2.5-5.0	D 1.0-2.5	R < 0.25	L 50-100
53213	1	H 9-11	U 2.5-5.0	D 1.0-2.5	R < 0.25	L > 100
53231	1	H 9-11	U 2.5-5.0	D 1.0-2.5	R > 0.5	L < 50
62222	1	H 11-13	U 1.0-2.5	D 1.0-2.5	R 0.25-0.5	L 50-100
42413	1	H 7-9	U 1.0-2.5	D > 4.0	R < 0.25	L > 100
43323	1	H 7-9	U 2.5-5.0	D 2.5-4.0	R 0.25-0.5	L > 100
52422	1	H 9-11	U 1.0-2.5	D > 4.0	R 0.25-0.5	L 50-100
53412	1	H 9-11	U 2.5-5.0	D > 4.0	R < 0.25	L 50-100
54323	1	H 9-11	U > 5.0	D 2.5-4.0	R 0.25-0.5	L > 100
54332	1	H 9-11	U > 5.0	D 2.5-4.0	R > 0.5	L 50-100
63323	1	H 11-13	U 2.5-5.0	D 2.5-4.0	R 0.25-0.5	L > 100
32431	1	H 5-7	U 1.0-2.5	D > 4.0	R > 0.5	L < 50
33413	1	H 5-7	U 2.5-5.0	D > 4.0	R < 0.25	L > 100
34432	1	H 5-7	U > 5.0	D > 4.0	R > 0.5	L 50-100
31432	1	H 5-7	U < 1.0	D > 4.0	R > 0.5	L 50-100
41413	1	H 7-9	U < 1.0	D > 4.0	R < 0.25	L > 100
333122	1	-	U 2.5-5.0	D < 1.0	R 0.25-0.5	L 50-100
51413	1	H 9-11	U < 1.0	D > 4.0	R < 0.25	L > 100

Appendix 4 Effects of buildings within classes

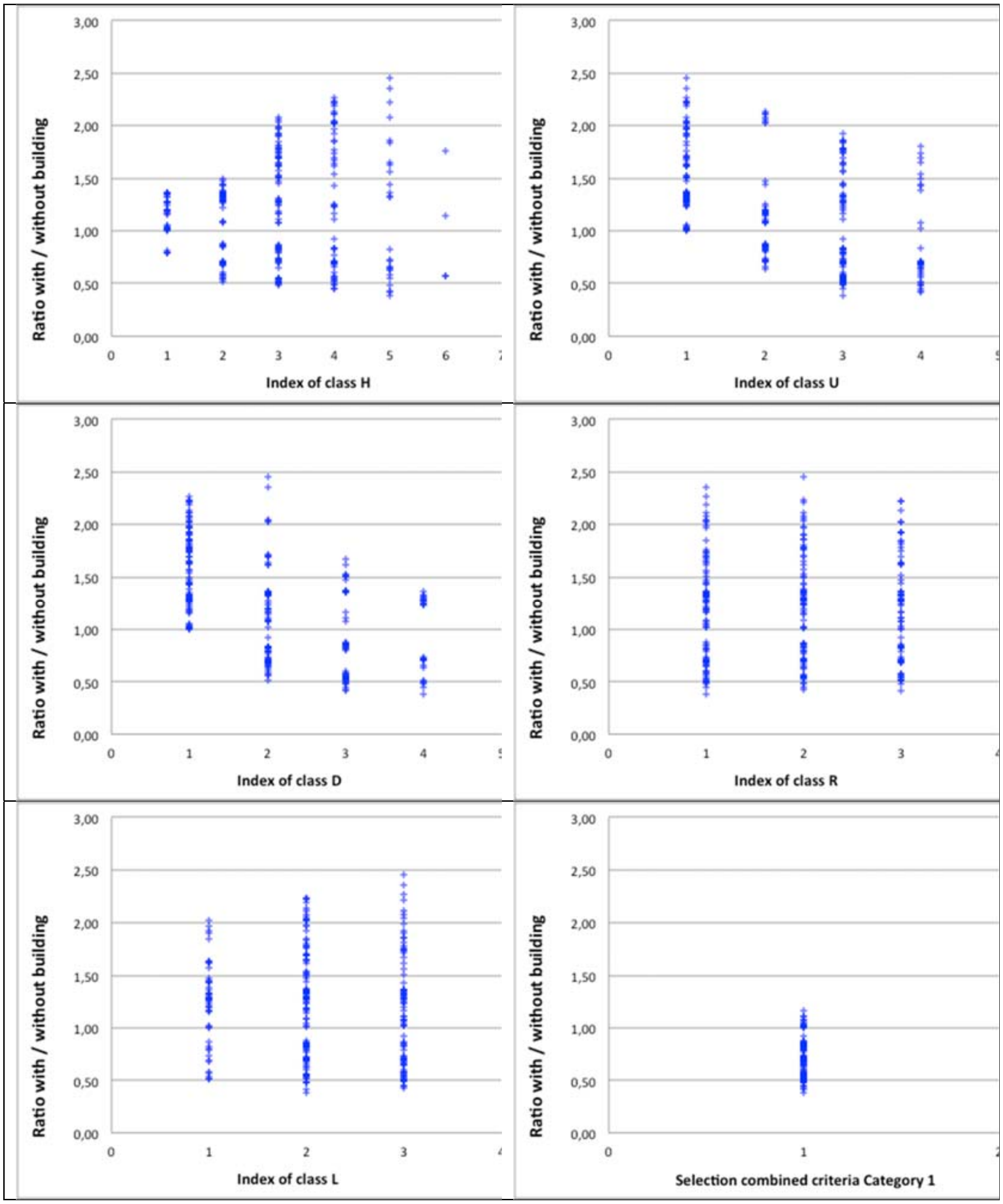

Figure A4-1 The average ratio of the concentrations at 100 meter from the source for all configurations with / without a building as a function of the class indexes stack (H), exit speed at the stack (U), diameter of the stack (D), ratio of the length and width of the building (R) and the length (L). Shown in the lower right are the ratios for the configurations that satisfy the combined criteria for 'Category 1' described in section 4.1. It shows 111 configurations, of which 96 have an ratio less than 1.0. The largest ratio is 1.16.

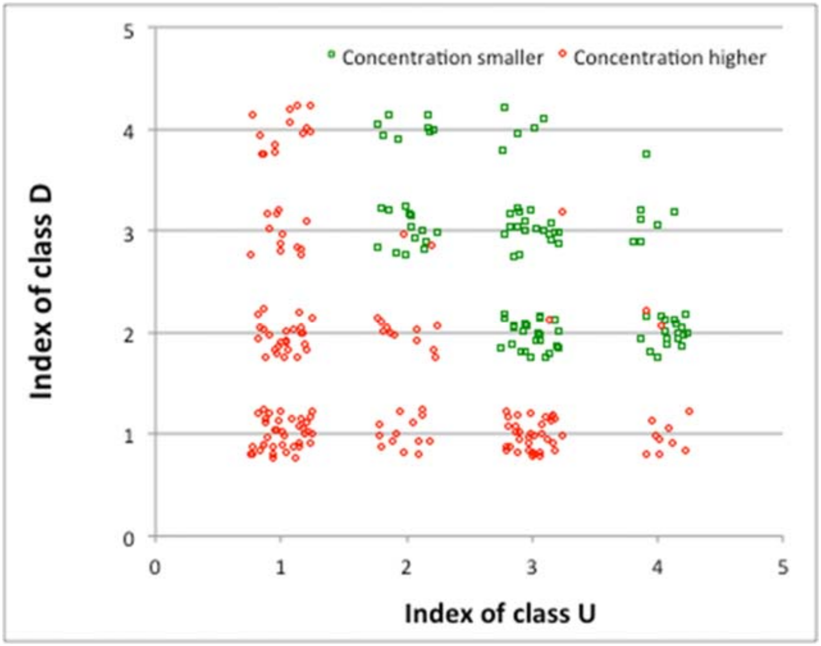

Figure A4-2 The effect of the building, green: concentrations smaller, red: concentrations higher, as a function of the exhaust speed and stack diameter. A small random number (between -0.25 and +0.25) was added to the class indexes to prevent all data being on top of each other.

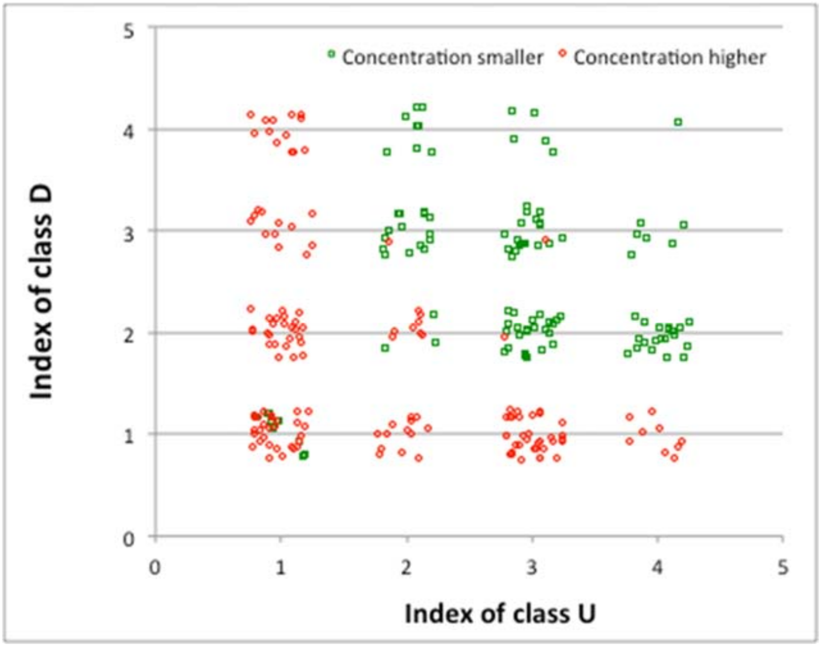

Figure A4-3 Similar to Figure B2-2, but here all configurations where the increase in concentrations due to the building is less than 10% (at 100 meter from the source) are shown in green.