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CHOOSING THE RIGHT DISPERSION MODEL FOR STACK DESIGN

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Dispersion models are essential tools in exhaust stack design. They predict how contaminants emitted from a stack will disperse in the outside air, and determine the stack parameters needed to keep the contaminants from impacting on fresh air intakes and other sensitive locations.

Many dispersion modelling software packages are available for use in stack design. The simplest models are screening-level tools that are relatively easy and fast to use. They provide first-cut estimates of pollution dispersion for individual exhaust stacks, under worst-case weather conditions. The most sophisticated models are finite-element models that solve the fundamental equations of atmospheric motion and simulate chemical processes in the atmosphere. These models can simulate smog episodes associated with widespread emissions from an entire region.

In addition to computer models, physical models can be used for dispersion modelling. Physical modelling consists of testing scale models in specially designed wind tunnels. For many applications, physical models provide the best combination of sophistication and practicality in modelling.

Figure 1: Example of looping effects during unstable conditions.

When choosing a dispersion modelling technique it is important to be aware of each model's limitations and the conditions under which it applies. Some models are very specialized in their applications. For example, a US EPA screening-level model called CTSCREEN, and its more detailed companion model, CTDM-PLUS, are intended to predict how pollutants emitted from a stack will behave when they meet a large, isolated hill or escarpment. The name CTSCREEN is short for Complex Terrain Screening-Level model, which is a misleading name, since it is intended mainly for isolated hills and escarpments, and may not be applicable in other types of complex terrain.

Other models are very general in their application, such as the current US EPA regulatory model, ISC3, and its upcoming replacement, AERMOD. Being general models, they tend to be simplistic in the way they handle special situations, such as dispersion around hills and buildings. They provide a first-cut in these situations, but for more reliable predictions, it is necessary to go to the appropriate specialized model.

In order to illustrate this hierarchy of dispersion models, one can divide the modelling applications into a few major categories and then consider which models are most applicable in each category. Perhaps the most basic category is that of tall stacks (significantly taller than nearby buildings) in level terrain. Other categories include tall stacks with a large hill or escarpment nearby, tall stacks in very complex terrain, and the corresponding categories for short stacks. For the purpose of this discussion, we define short stacks as having a height above grade that is less than 2.5 times the height of one or more nearby buildings.

In each of these categories, the stack emissions will encounter unique conditions of wind flow, turbulence, and other meteorological phenomena that will be handled better by some dispersion modelling techniques than others. Figure 1 shows a phenomenon, sometimes called convective looping, that is the result of convective thermals that develop on clear days with light winds. Downdrafts associated with these thermals can cause exhaust gases emitted from a tall stack to impinge on the ground at a relatively short distance downwind. When modelling tall stacks, it is important to use a model that handles this phenomenon. AERMOD, the US EPA's new regulatory model (still being beta tested) is one of the most up-to-date models for handling convective conditions.

When modelling short stacks on buildings, on the other hand, it is not essential for the model to handle convective looping. Looping is much less of an issue in this case, since the turbulence generated by air flowing over the buildings tends to dominate over thermals.

Figure 2 shows a comparison of selected modelling techniques for short stacks in built-up terrain. First we have the screening-level models, which include the US EPA's model, SCREEN3, and the exhaust dilution calculations presented in Chapter 43 of the ASHRAE HVAC Applications Handbook. These models are very simplistic and do not reliably account for the wide range of building geometries and stack configurations that may be encountered. SCREEN3 has the added disadvantage of being intended to predict impacts only at ground-level locations, beyond the near wake of the building where the stack is located (i.e., beyond about 3 times the building height). It does not predict impacts at locations very close to the stack, such as fresh air intakes, windows or doorways of the same building.

Next in line are the more advanced regulatory numerical models, which include the US EPA's models, ISC3-PRIME and AERMOD. These models remain simplistic in their treatment of the effects of building geometry, and as such, are still a first cut.

Short Stack (<2.5 H_b)
Built-Up Terrain

SCREEN3
- simplistic treatment of building wakes
- max. 1-hour concentration
- mainly off-site, ground-level receptors, beyond $3H_b$

ISC3-PRIME/AERMOD
- more realistic treatment of building wakes
- still simplistic for complicated geometries

ASHRAE HVAC APPLICATIONS HANDBOOK
- screening-level model
- receptors on same building as stack only
- max. 10-minute concentration
- moderate degree of realism
- requires judgement

WIND TUNNEL SIMULATION
- highest degree of realism
- generally covers all meteorological conditions
- friendly requirements for input weather data
- receptors within about 3000ft
- best with non-buoyant exhausts

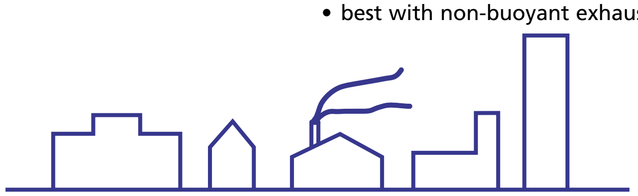

Figure 2: Comparison of selected modelling techniques.

The best specialized model for short stacks in built-up terrain is physical modelling, using a scale model in a boundary-layer wind tunnel (See Figure 3). This is the model of choice when the highest degree of realism is desired. It is a relatively practical modelling technique, as far as specialized models go, and can account for any building geometry, no matter how complex. Since wind tunnels have fixed physical dimensions, there are limits to the distance away from a stack that impacts can be predicted (about 3000 ft at typical model scales). This limitation, however, is not usually a problem for short stacks, since they tend to produce maximum impacts at relatively short distances away.

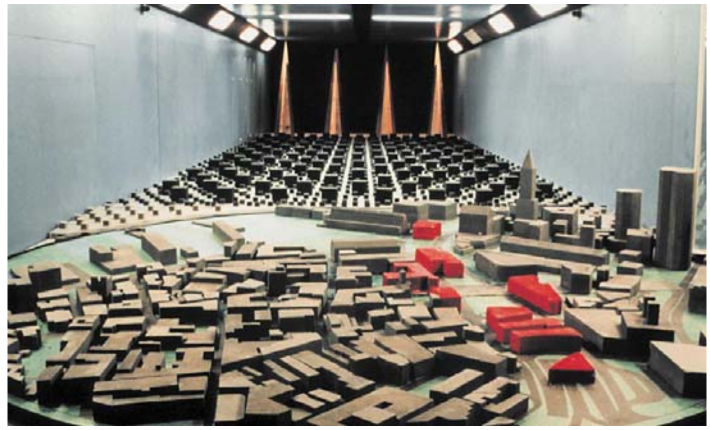

Figure 3: Boundary-layer simulation in RWDI's wind tunnel.

Another modelling approach that has been used to study exhaust dispersion for short stacks on buildings is Computational Fluid Dynamics (CFD). This is a sophisticated 3-dimensional computer modelling technique with wide-ranging applications. It has been demonstrated to be successful in modelling the behaviour of emissions from stacks on buildings with simple shapes. CFD currently does not have the same ease of modelling a wide range of wind angles and wind speeds as does physical modelling, but it provides high-resolution results and has other features that are useful in specialized applications.

It is clear that there are many options available for dispersion modelling. The best option should strike a balance between the amount of effort needed to run the model and the degree of accuracy required in the results. The wrong choice can lead to under-design or over-design of exhaust stacks, and either one can be a problem. Choosing the right exhaust dispersion model is an all-important first step in a successful assessment of stack designs.