

## in high-rise residential buildings – implications for ventilation design

# Infectious Disease Spread

*In the SARS epidemics in 2003, cluster of cases occurred in high-rise residential (HRR) building blocks, especially in Hong Kong, which gave rise to the concern of the possible roles of air flow in all other airborne infectious disease spread. In this paper, the multiple parallel airborne transmission routes are discussed in a HRR. In particular, we closely investigated one of the most likely virus-spread airflow paths, which are related to single-side ventilation air flow through open windows caused by buoyancy effects. Both tracer gas technique and CFD (computational fluid dynamics) techniques have been employed to quantify the amount of the exhaust air coming out of the lower floor that re-enters the open window at the adjacent upper floor. It was found that the upper floor air can contain up to 7 % of exhaust air directly from the lower floor. The results can well explain the finding that RNA fragments of SARS Corona-Virus (CoV) were detected within the sampled deposits on the window sills of the upper floors of the two index patients' flats during the SARS outbreak. Implication for ventilation design and infection control in HRR will be discussed.*

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Natural ventilation plays two essential roles traditionally in our buildings. On one hand, ventilation can modulate the indoor temperature for better thermal comfort in summer since outdoor air is usually lower than indoors; on the other hand, it also helps to dilute indoor air pollutants and improve indoor air quality in most cases. The required quantity and quality are actually different for these two purposes. The roles of natural ventilation in modern high rise residential buildings are more complicated. Especially, in the rapid developing Asian regions, a majority of the population live in high-rise, multiple-house-

holds apartment buildings. The climatic conditions also render airconditioning widely applied, with the window-type and split-unit type airconditioners dominating in the residential buildings. Ventilation is provided via open windows, with exhaust fans provided in the toilets and kitchens. The exhaust air is typically not centrally stacked, but left to drift around the building blocks. This can potentially have many unwanted consequences for multi-households, multi-story high-rise buildings [6]. On the ordinary days, it's not uncommon for the residents to detect from the smell in his own unit what the neighbor is cooking – a sign

of cross-contamination of the ventilation air. With respect to infectious disease control, this inter-flat or inter-zonal flow becomes a serious issue.

When airborne infectious disease spread is concerned, there are also a number of other parallel transmission routes from person to person. Interior corridors are typically poorly ventilated though the residents tend to spend little time there; lift tend to be crowded, and lift lobbies are usually poorly ventilated as well. Depending on the floor plan, direct, horizontal air flow from one unit to the adjacent unit can occur. In particular, to maximize the land-use efficiency, high plot-ratio, defined as the total floor area over the land area, can reach to 10 in urban development. This tends to result in both horizontally-close units and high-rise designs (Figure 1), which increase the risk of air-borne infection, spread [10]. It appears that infection risks associated with these routes have not been well studied, and many infectious diseases like common cold, influenza and tuberculosis may be transmitted through these routes.

This investigation is focused on the vertical transmission pattern in high-rise residential buildings observed during the SARS outbreak in the spring of 2003 in Hong Kong. In apartment building A, which is about 30 storeys high, and where five households were affected with eleven SARS infection cases, RNA fragments of SARS virus were detected within the sampled

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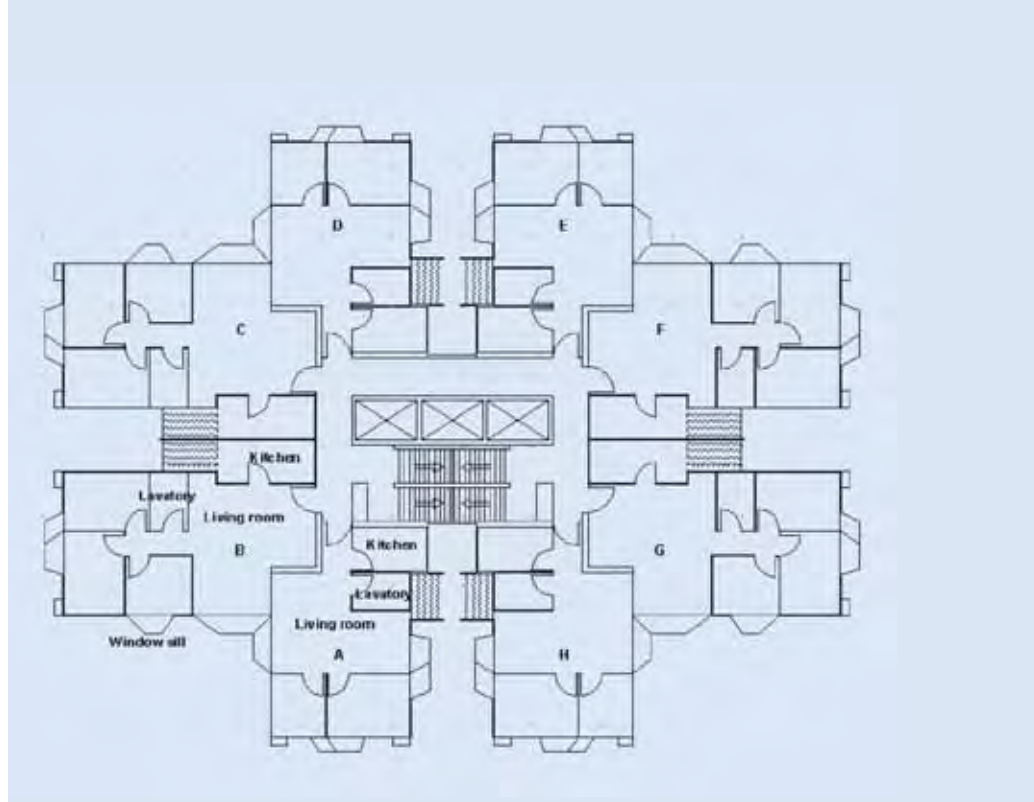
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deposits on the window sills of the upper floors of the two index patients' flats; and in one of these two upper floor households there were no infected SARS cases. In another high-rise building B, all the six infection cases in three households occurred along one vertical block. In the widely-publicized outbreak in another residential estate, which includes five blocks of 30 storeys apartment buildings, and where a total number of 321 infections occurred, only one case occurred below the 8<sup>th</sup> floor. While the transmission paths of such large scale outbreaks remain a myth up to the present moment [10], it appears that there was a vertical spread pattern.

Our hypothesis is that, on windless days, the outflow from a window on the lower floor will re-enter the adjacent upper floor, and therefore bring the virus-laden droplets generated by an index patient upstairs. For high-rise buildings, there may exist an upward "cascade" air flow, so that the disease can be transmitted from a lower resident all the way to the top floors. The objective of this project is to reveal the mechanisms of this airflow by actually quantifying the fraction of the lower-floor exhaust air within the intake air of the adjacent upper floor. This paper reports the preliminary finding of this study.

### SINGLE SIDE VENTILATION

The driving forces of natural ventilation can be classified into two categories: one is the wind pressure, and the other is the buoyancy/stack effect caused by temperature differences. Single ventilation refers to the purposely provision of vent openings on the single side of a room space, so that no cross-ventilation is possible. The original intention is to minimize the effect of wind pressure, and maximize the stack effect due to indoor/outdoor temperature differences. Typically, indoor temperatures are higher than outdoors under natural conditions, outdoor cold air tends to enter the room at the lower part of an open window and at the same time warm air tends to leave the room at the upper part of the window. In buildings with multiple story and multiple flats on each floor, the overall air flow path through the multiple openings can be highly variable depending on



**Typical floor plan for high-rise residential apartment buildings, typically around 30 storeys high. In this plan, eight units on each floor share interior corridors and the three lifts.**

- FIGURE 1-

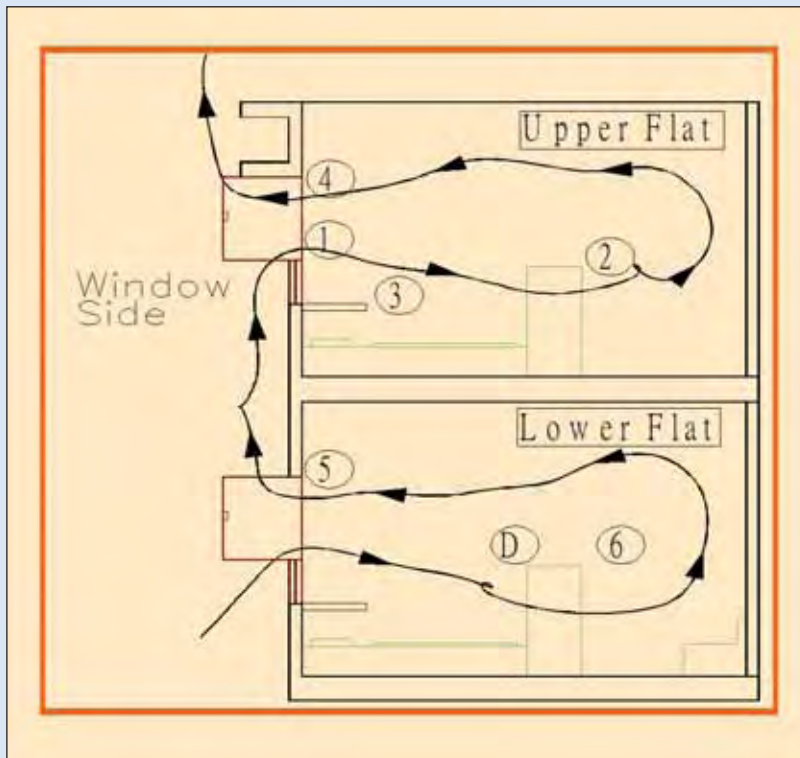
the wind direction and wind speed. With the floor plan as illustrated in Figure 1, residents tend to close their doors when entering their home, so that essentially single side ventilation situation arises. Under high wind conditions, cross ventilations may still be significant via door gaps, but this often causes undesirable horizontal air contaminant transport from one unit to the other. In fact it so happened in an extreme case that VOC (volatile organic compounds) emissions from paint spray during a decoration was suspected to be the cause of an infant death of the neighboring unit. Here it should be emphasized that under low wind conditions, single-side ventilation will be the dominant air flow pattern, as illustrated in Figure 2 and 3. From the point of view of air pollutant accumulation, the worst-case occurs on windless days. In the Hong Kong climate, the windless days can occur in March and April, which happened to be the period during which SARS case clusters. According to our previous survey, residents in Hong Kong may only switch on the exhaust fans in their kitchen or toilets when these two rooms are actually used. In this case, buoyancy due to indoor-outdoor temperature difference will be the only driving force. In multi-story high-rise buildings, it is suspected that this single side air flow may cause vertical transmission of air-

borne infectious diseases. In this study, we attempt to quantify the percentage of air from the lower floor present in the upper floor via this route.

### INVESTIGATION METHODS AND RESULTS

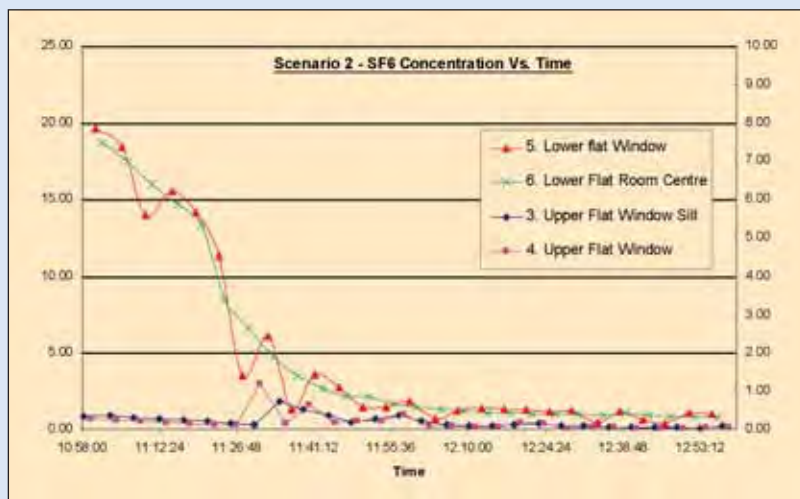
#### *Onsite tracer gas measurements*

This investigation is performed using experimental tracer-gas and flow visualization technique. The building investigated has single-side natural ventilation via open windows. Two rooms located at immediate upper and lower floors, which have windows flush with the façade (Figure 2), were selected for site measurements. The floor to ceiling height is about 2.7 meters, and the room depth is about 5 meters, and the width is about 3.5 meters. This façade feature is similar with buildings A and B as described in the introduction, where clusters of SARS case occurred and vertical transmission patterns were observed. The measurements were continuously conducted from one month in February and March respectively in 2004 and 2005. The experiment was conducted in the spring time because it was the season of SARS outbreak, and is also the high season of common-cold and influenza occurrences in Hong Kong. During the periods of measurement, the outdoor temperatu-



Possible air flow path associated with single side ventilation and locations of the tracer gas dosing point (D), and sampling point (1 to 6).

- FIGURE 3-



Monitored tracer gas concentrations in the two flats when tracer gas was released in the low floor.

- FIGURE 4-

res varied from 10.6 to 24.0 °C with the mean of 17.3 °C. The indoor temperatures of the two rooms varied 12.8 to 23.3 °C (mean = 18.4 °C) and 14.1 to 23.1 °C (mean = 18.7 °C), respectively.

In the on site experimental studies, SF6 was released at a constant release rate in the center of the single room flat in the lower floor, while the SF6 concentration levels at six points were monitored simultaneously using a B&K1302 multi-gas monitor (Figure 3). An example of the monitored concentrations upstairs and downstairs are

shown in Figure 4. At the same time, a smoke generating machine released smokes into the lower flat, and air movement of the exhaust air from the lower floor, and possible direct re-entry into the upper floor can be visualized by the smoke movement. Since we cannot control the weather, the flow phenomena we observed would be the combined results of both the wind pressure and buoyancy effects.

Based upon these monitored tracer-gas concentrations, an index, called mass fraction  $M$ , can be worked out. For



Two rooms located in adjacent upper and lower floors in a student dormitory were selected for tracer gas measurements.

- FIGURE 2-

instance,  $M_{6-3}$  can be calculated based upon the monitored tracer gas concentration at point 3 and 6, which would indicate the fraction of the air originating from point 6 but present at point 3. Using the one month data obtained in 2005, such an index is plotted as Figure 5, it can be seen that the maximum value of the mass fraction is 0.07, which means 7 % of the air in the upper floor directly comes from the lower floor. It appears that higher wind decreases the re-entrance slightly.

### CFD simulation

CFD (computational fluid dynamics) simulation technique [3; 4; 5] was also employed. Both transient and steady-state simulation results have been obtained using the standard  $k-\epsilon$  turbulence model. The reliability of the numerical simulation has been first checked with good quality laboratory experimental results obtained from Denmark [2]. In Heiselburg's laboratory experiments, the transient air exchange via a single-side ventilation window was measured using fast-response anemometry system, and the indoor surface and outdoor air temperature differences were closely monitored.

Presented in Figure 6, is the simulated air flow path-lines and the velocity magnitude through two open windows of two adjacent vertical floors. In general, the velocity caused by buoyancy alone is rather low, with the maximum around 0.5 m/s, as indicated by the

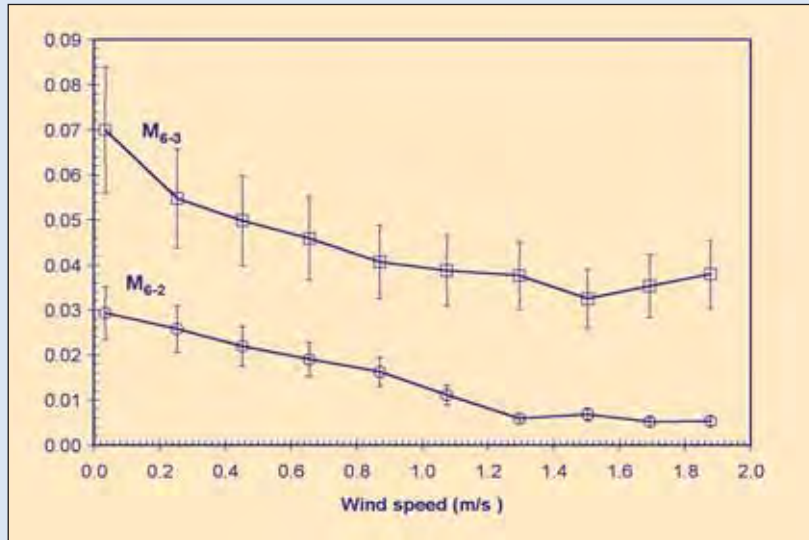
colored zones in Figure 6, 7, and 8. On a windless day of outdoor air temperature of 20 °C and indoor room surface temperature of 28 °C, it can be seen in Figure 8 that the outdoor air enters the lower room through the lower part of the window, and leaves the room at the upper part of the window. At the same time, it can be clearly seen in Figure 7 that a portion of the outflow from the low floor re-enters the upper room through the lower part of the upper window. It looks as if the warm exhaust plume from the lower floor functions as an air curtain, with which ambient air has to mix first to enter the room. Based upon the calculated velocity across the two window openings, air change rates through the two window openings have also been calculated, and tracer gas have also been added into the lower room, and similar results as for the onsite measurements have been obtained.

**CONCLUSION AND IMPLICATIONS**

During the SARS outbreak, the presence of SARS virus RNA strings were found in the window deposits, and this study revealed the virus could have been transported up by the single side ventilation air flow. It should be noted that, depending on the window opening habits of the residents, this could be a continuous transmission route. More epidemiological data on other aerosol transmitted diseases would also be helpful to further confirm this significant transmission route. The confirmation of the transmission route can have a number of implications to both building design and infectious disease control. With respect to the former, windows flush with façade should be avoided, and ledges added above the window can reduce the transmission to a certain extent. It appears that complete avoidance of this cross contamination through ventilation control is costly and difficult. With respect to the latter, more targeted and sooner intervention can be implemented in case of any highly-infectious disease outbreaks, which may be more cost-effective.

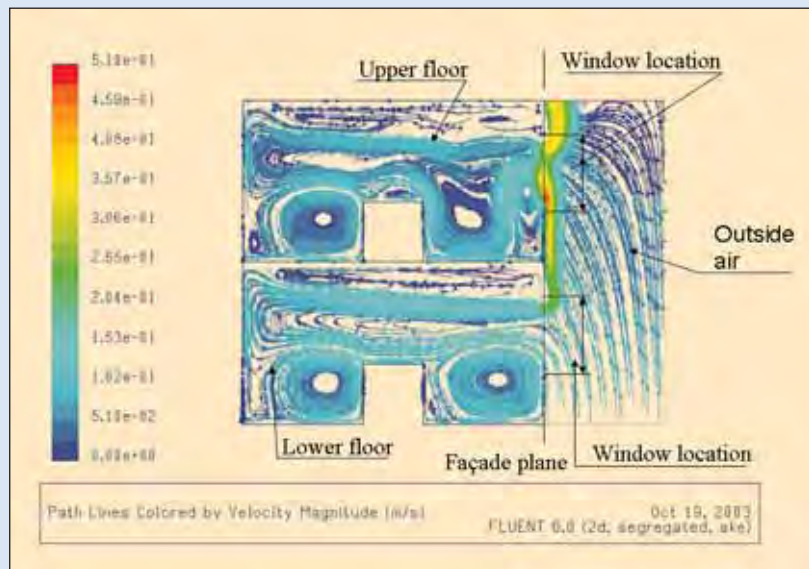
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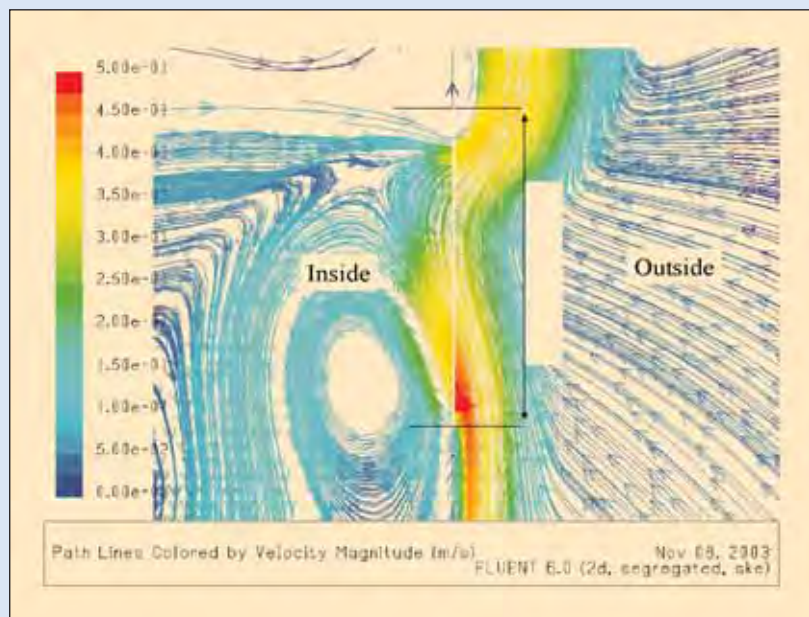
The mass fractions indicating the presence percentages of air coming from the lower floor at two points in the upper floor.

- FIGURE 5-



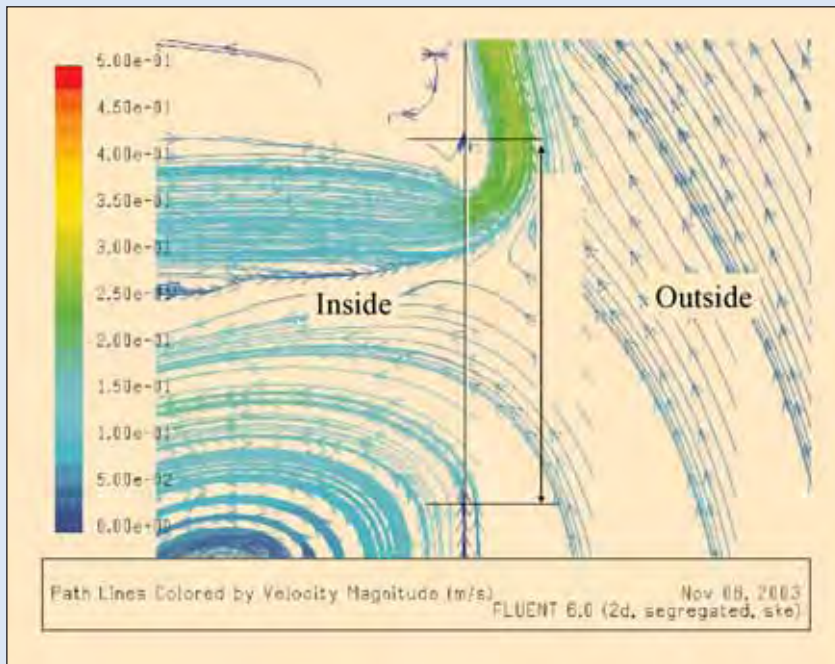
Air flow patterns indicated by flow path lines.

- FIGURE 6-



Airflow path lines across the window at the upper floor.

- FIGURE 7-



Air flow path lines across the window at the lower floor.

- FIGURE 8-

number of students in undertaking the site measurements. The project is being funded by the Research Grant Council, Hong Kong SAR government under the project No. PolyU 5125/04E.

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## VAN BEEK INGENIEURS 25 JAAR

Van Beek Ingenieurs viert dit jaar haar 25-jarig jubileum. Ooit begonnen onder leiding van oprichter Cees van Beek, is Van Beek uitgegroeid tot een vooraanstaand adviesbureau voor softwareontwikkeling en advisering op het gebied van efficiënt energiegebruik. In 2001 is Van Beek Ingenieurs onderdeel geworden van Priva en heeft het bureau een verdere groei ingezet zowel binnen Nederland als in de haar omringende landen.

## ONLINE ENERGIEBESPARING

Het verkennen van Energiebesparingsmogelijkheden voor bestaande woningen kan vanaf internet via de energiebesparingsverkenner.nl. Deze website laat zien hoe energiebesparende maatregelen de woonlasten omlaag kunnen brengen. Dankzij dit instrument kunnen onder meer bouwbedrijven en woningbouwcorporaties hun klanten informeren over energiezuinige maatregelen.

## DYKA VIJFTIG JAAR

Dyka vierde afgelopen maand haar vijftig jarig bestaan met een symposium over duurzaamheid. Albert van Dijk, loodgieter in Steenwijk, richtte in 1957 het bedrijf op. Het begon met PVC-hulpstukken die snel en gemakkelijk in een leiding te installeren waren. Dyka is in Nederland tegenwoordig marktleider in binnenhuisafvoersystemen voor de woning- en utiliteitsbouw.

## CURSUS EPN HERZIEN

De wijzigingen van de energieprestatiecoëfficiënt (EPC), zowel in hoogte als in de rekenmethodiek, hebben nogal wat voeten in de aarde. Het Opleidings- en Ontwikkelingsfonds voor het Technisch Installatiebedrijf (OTIB) ontwikkelde daarom een geheel nieuwe training voor projectleiders en ontwerpers om de kansen die dit biedt inzichtelijk te maken en de installateur te leren deze kansen te benutten.