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R.C. Diamond, H.E. Feustel, and D.J. Dickerhoff

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# Ventilation and Infiltration in High-Rise Apartment Buildings

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**Synopsis**: Air flow, air leakage measurements and numerical simulations were made on a 13-story apartment building to characterize the ventilation rates for the individual apartments. Parametric simulations were performed for specific conditions, e.g., height, orientation, outside temperature and wind speed. Our analysis of the air flow simulations suggest that the ventilation to the individual units varies considerably. With the mechanical ventilation system disabled and no wind, units at the lower level of the building have adequate ventilation only on days with high temperature differences, while units on higher floors have no ventilation at all. Units facing the windward side will be over-ventilated when the building experiences wind directions between west and north. At the same time, leeward apartments did not experience any fresh air--because, in these cases, air flows enter the apartments from the corridor and exit through the exhaust shafts and the cracks in the facade. Even with the mechanical ventilation system operating, we found wide variation in the air flows to the individual apartments. In addition to the specific case presented here, these findings have more general implications for energy retrofits and health and comfort of occupants in high-rise apartment buildings.

## 1.0. Introduction & Literature Review

Quantifying the impact of infiltration on energy use in buildings has stymied researchers and practitioners alike. And while the difficulties of measuring and modeling its effect are widely acknowledged, there is agreement on its importance. The effect of infiltration on energy use in a high-rise apartment building can be seen directly in **Figure 1**. The figure plots annual energy consumption per floor in a 12-story apartment building in Pittsburgh, Pennsylvania. The energy consumption on the lower floors is 28% higher than the mean, and decreases with height until the next-to-the-highest floor where the consumption is 32% lower than the mean. (Energy consumption on the top floor is higher due to conduction losses through the roof.) The reason for this variation in energy use is the infiltration due to stack effect--because of pressure differentials due to inside-outside temperature differences, air in the building rises up the vertical shafts (stairs and elevators) and draws in colder outdoor air at the base of the building. So lower apartments get a greater burden of outdoor air which poses an energy penalty in winter, while the upper units get warm air from below, but the lack of outdoor air to these units poses an indoor air quality penalty.

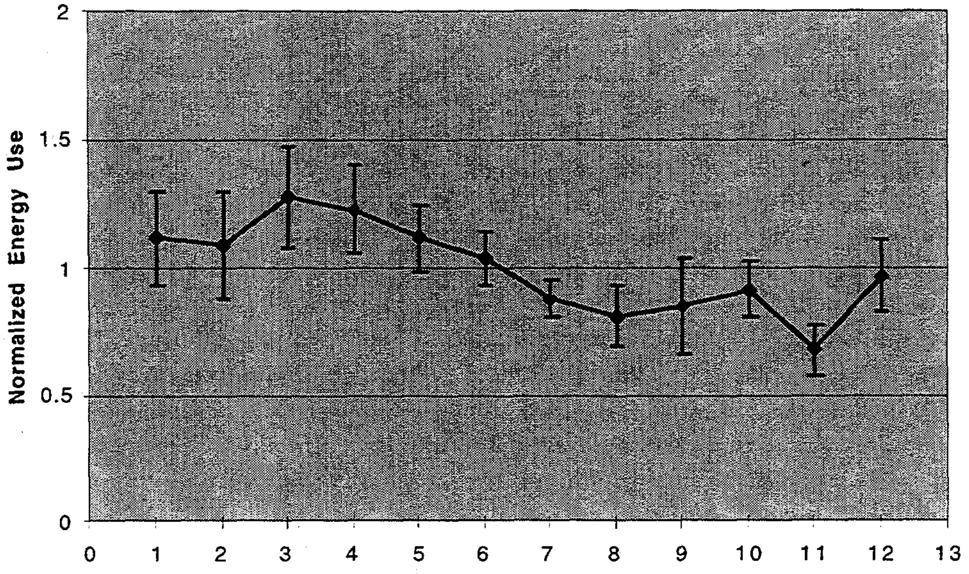

**Figure 1**. Annual electricity consumption per floor for a 12-story apartment building in Pittsburgh, Pennsylvania. Consumption data have been normalized by mean values. Error bars show one standard deviation above and below the mean.

To address these issues of balancing energy efficiency and health, multi-story residential buildings often have mechanical ventilation systems to provide adequate outside air for comfort and health. The performance of these systems, however, is often less than satisfactory, due to poor design, sporadic maintenance, and interactions with both natural infiltration and occupant behavior.

The literature on air flow and air leakage measurements in high-rise multifamily buildings is quite limited. As we are not aware of any review of these topics for North American multifamily buildings (both highrise and lowrise), we present a brief chronological summary of the research on these topics below.

A pioneering study by Tamura and Wilson measured the pressures across the exterior envelope of a nine-story building in Ottawa, Canada (Tamura and Wilson, 1966). They made measurements with the mechanical ventilation system both on and off, and concluded that the pressure differences across the building envelope depends on the distribution of the openings in the envelope and the ratio of resistance to air flow inside the building to that across the exterior wall.

An early study on measurements of air leakage in multistory apartment buildings was performed by C.Y. Shaw in 1980. He conducted small-scale pressurization tests on the exterior walls of apartments in a multi-story building and found floor-wall joints, windows and window sills to be the major leakage sites (Shaw 1980).

One of the first measurements of both air leakage and infiltration in a high-rise apartment is reported by Feustel et al. (1985), where fan pressurization, tracer gas and pressure measurements were made in a 9-story dormitory building in Berkeley, California. The measurements were then used in an airflow simulation model to study the importance of both wind and stack effect in determining air infiltration.

Using tracer gas measurements in three typical low-income apartment buildings in New York City, Commoner and Rodberg found natural infiltration rates of 1.08, 0.58 and 1.01 ACH, about twice the leakage calculated from window dimensional measurements. They determined that the "extra" leakage was to adjacent apartments and common spaces (Commoner and Rodberg, 1986).

Modera et al., working with staff from the Minneapolis Energy Office, measured air leakage in a six-unit building in Minneapolis (Modera et al., 1986). Using six blower doors simultaneously they showed that the average leakage for each apartment was 1600 $cm^2$ (13 $cm^2/ m^2$) and that only 40% of the air leakage was directly through the exterior envelope. The remainder was either to the adjacent units or in the interstitial spaces between the apartments. These leakage areas were used in conjunction with a multizone air infiltration model to determine the air flows between apartments and to the outside.

Two blower doors were used to measure air leakage in two three-story apartment buildings in Chicago (Diamond et al., 1986). Leakage areas of 2460 $cm^2$ and 1880

$cm^2$ were measured for the two apartments, which when normalized by floor area were both 19 $cm^2/m^2$. While the apartments were significantly leakier than the one measured by Modera, roughly the same fraction (60%) of the leakage was to the other apartments.

Blower door measurements in a study of eleven multifamily buildings in upstate New York showed an average pre-retrofit leakage rate of 35.5 ACH @ 50 Pa, implying a natural ventilation rate of over 1 ACH (Synertech, 1987).

Bohac and his colleagues tackled a six-story apartment building in Minneapolis, Minnesota in 1987 with several tracer gas and fan pressurization techniques. They were able to estimate airflows between apartments, but concluded that in this building, air exchange was dominated by patterns of window openings (Bohac, 1987).

Researchers in the Pacific Northwest took measurements in nine new motel-style multifamily buildings (where each unit has its own outside door) and reported estimated average leakage rates ranging from 0.08 to 0.30 (median 0.19) ACH, well below the ASHRAE 62 Standard of 0.35 ACH (Baylon and Heller, 1988).

Measurements of low-income rowhouses in Philadelphia showed an extremely high air leakage of 55 ACH @ 50 Pa, with up to 30% of the flow to adjoining units (Cameron, 1990). They attributed the high leakage to the characteristics of the row house construction and the generally poor condition of the houses.

Researchers found that even in a two-story apartment building that ground-floor apartments can have more than double the heating bills of upstairs apartments due to internal air-leakage patterns and heat flow (McBride et al., 1990).

Modera and Herrlin analyzed inter-zonal leakage using two blower doors in a controlled test set-up. These data were used in a computer simulation (Movecomp) to determine air flows in a multifamily building under different wind conditions and *measurement protocols. They found that uncertainties due to wind fluctuations for wind* speeds under 5 m/s did not exceed 10% (Modera and Herrlin, 1990).

Shaw and his colleagues in Canada measured two high-rise apartment buildings using a system of two pressurization set-ups and tracer gas equipment. One blower door was used in the individual apartment and the other was used to pressurize the entire building. The pressures between the test unit and the adjacent units were balanced to minimize the air leakage between the party walls (Shaw et al., 1990).

Harrje et al. compared three different tracer gas techniques to measure air infiltration in a high-rise apartment in Princeton, New Jersey. The tests were Constant Concentration Tracer Gas (CCTG), Multi-tracer Mass Spectroscopy (MTMS) and Air Infiltration Monitors (AIMS). The study reports the strengths and weaknesses of the three methods (Harrje et al., 1990).

Hayes reports the results of an audit of a rehab of a four story brick warehouse converted to apartments for the elderly. The new construction consisted of sheet-rocked boxes inside the brick walls of the original building, with large spaces for air flow between the old and new walls. But the individual apartments tested quite tight for air leakage. Hallways tested tight, too. Her conclusions were to focus air sealing on bypasses--especially between old and new building envelopes, and concentrate on improving mechanical ventilation systems with dampers and better controllers (Hayes, 1992).

Mark Kelley (Kelly et al. 1992) measured the air leakage pre-and post-retrofit in a high-rise apartment in Revere, Massachusetts. They found an average pre-retrofit leakage for 17 of the apartments of 532 CFM at 50 pascals, and a post-retrofit leakage of 449 CFM at 50 Pascals, a reduction of 15%.

Perhaps the largest study to date on ventilation in multifamily buildings was conducted by the New York State Energy Research and Development Authority (Shapiro-Baruch, 1993). They developed and tested a ventilation audit in 10 multifamily buildings, finding measured airflow rates to be on average 32% less than the design values. Energy use for mechanical ventilation varied widely from building to building, from less than 2% to more than 20%. They identified poorly designed and poorly operated supply air systems as the source of many indoor air quality problems.

Monitoring of two multifamily apartment buildings in Chicago, Illinois, was undertaken in the Spring of 1993 by a team of energy researchers from Argonne National Laboratory, the University of Illinois, and Lawrence Berkeley Laboratory. They performed ventilation and infiltration measurements in two multifamily apartment buildings to determine the leakage characteristics for two types of retrofits and adequate levels of ventilation for air quality throughout the building. In one of the two buildings, blower-door measurements showed relatively high air-exchange rates. Pressure measurements in wall cavities indicated that internal and exterior walls experienced pressures close to those outside. Construction details of the walls showed that the use of metal studs, with break-outs for electrical wires, provided holes that connected all wall cavities of a dwelling. Depressurization of one zone caused air flows from the outside through all direct flow paths and through all wall cavities to openings in the walls (e.g., electrical outlets), including interior walls. The building constructed with wooden studs had lower leakage levels. The pressure level for interstitial spaces was much closer to the level of the depressurized zone than to the ambient pressure (Katrakis et al., 1994).

Researchers from LBL used a single-blower-door technique for measuring leakage in multifamily buildings in 1993 in two New York apartment buildings. One apartment was pressurized and depressurized to ±50 Pa, and the resulting pressures were measured in adjacent apartments. By incorporating the pressures measured in the adjacent apartments (1-15 Pa) into a mass balance equation, they were able to calculate that approximately 50% of each apartment's leakage was to outside in one building, and that a significantly larger fraction was to outside in the other (Dickerhoff et al., 1994).

Vicky Hayes and Ian Shapiro-Baruch report on a recently funded project by the New York State Energy Research and Development Authority (NYSERDA) to assess the types, effectiveness and energy efficiency of ventilation systems in multifamily buildings in New York State. They collected detailed information for ten sites and additional information on another 50 sites. They concluded that much of the uncertainty surrounding ventilation codes and standards could be eliminated if an accurate method of quantifying air flow in a multifamily building was available (Hayes and Shapiro-Baruch, 1994).

What emerges from a review of these studies is the paucity of information characterizing air leakage in multifamily buildings and the typically poor level of control in the provision of ventilation for the building occupants. Several of the articles mention reasons for why there are problems in measuring, modeling and designing ventilation systems for high-rise multifamily buildings, but few offer any solutions. Routine questions from the single-family literature such as how to define a reference pressure for blower door measurements are currently unanswerable for multifamily buildings. And we have little knowledge on how to characterize and determine the leakage distribution in different types of multifamily construction.

## 2.0 Project Description

Our recent activity in this area came about through the DOE-HUD Initiative, a response to the U.S. National Energy Strategy's directive to improve the energy efficiency in Public Housing. Under the Initiative's guidance a collaborative project was established to demonstrate energy efficiency in Public Housing as part of a utility's Demand Side Management (DSM) Program.

The demonstration site is the Margolis Apartments, a modern 150-unit high-rise apartment building for the elderly and handicapped, located in Chelsea, Massachusetts, in the greater Boston, Massachusetts, metropolitan area (Figure 2).

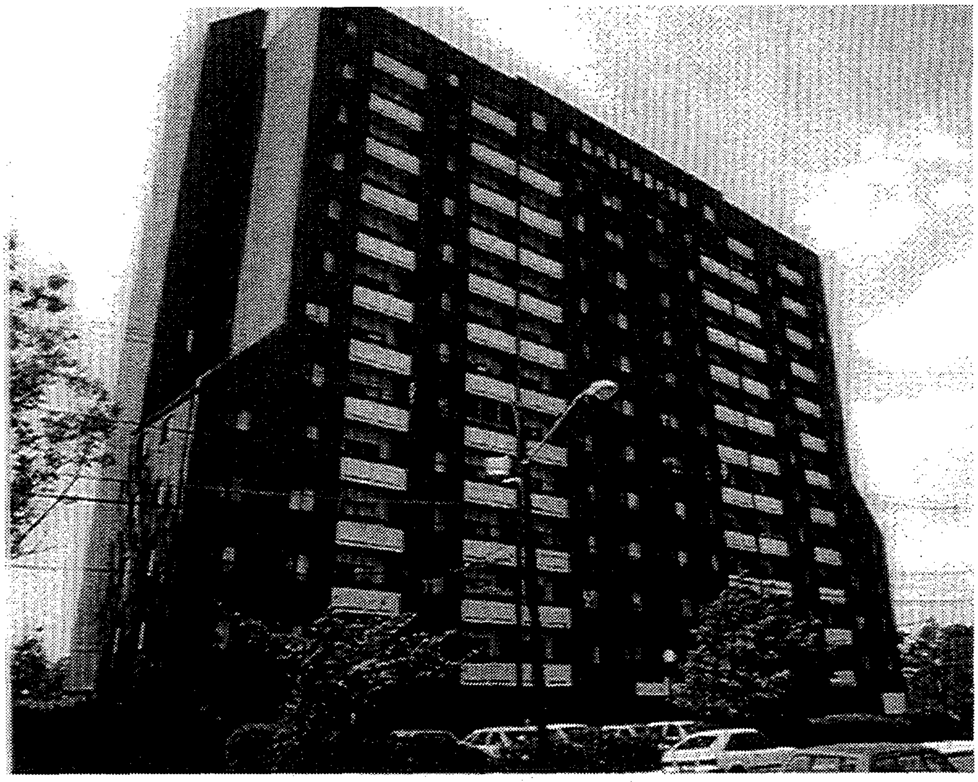

**Figure 2**. The Margolis Apartments, Chelsea, Massachusetts.

The Margolis Apartment building was designed and built in 1973-1974 and is typical of high-rise construction from that period. The building has thirteen stories and is of steel-frame construction. The individual apartments have electric-resistance heaters in each room, and double-pane windows and sliding balcony doors. Figure 3 shows a typical floor plan of the building.

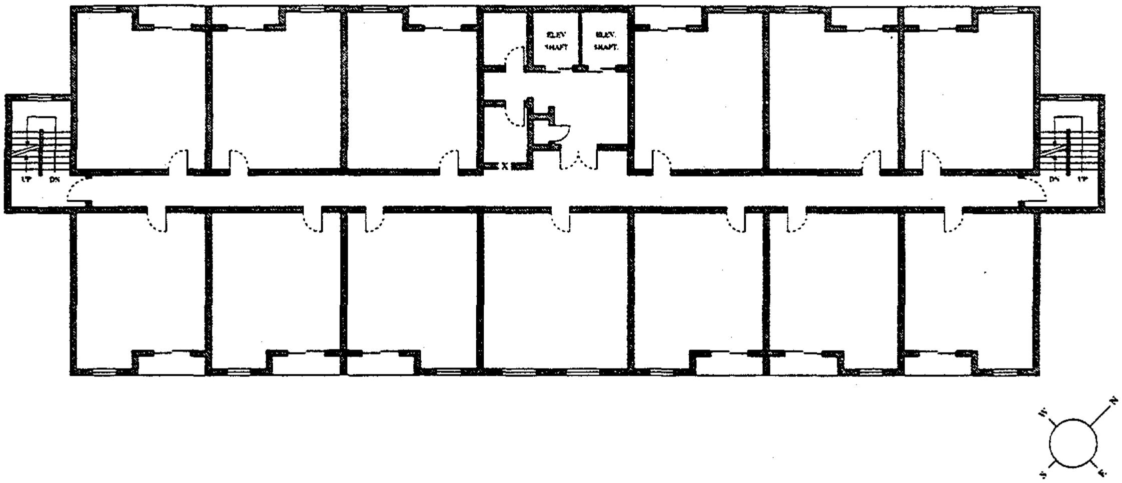

**Figure 3**. Typical floor plan (floors 6-12), Margolis Apartments, Chelsea, MA. The "x" shows the location of the supply ventilation register for each corridor.

The building has a mechanical ventilation system, with kitchen and bathroom exhaust fans for each apartment leading into separate vertical shafts which have additional exhaust fans located on the roof. The supply air system for the building is provided by a fan and heating unit on the roof that connects to a vertical shaft which has supply registers to the main hallway on each of the floors (Figure 4). Supply air then enters the apartments by a slot under the front door of each unit.

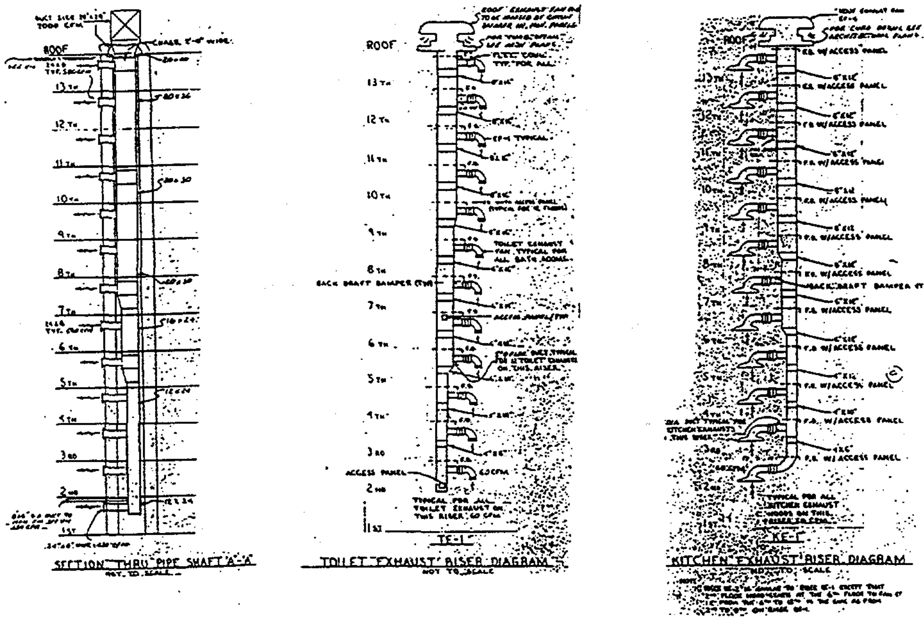

**Figure 4**. The central ventilation supply trunk and typical exhaust risers from kitchen and bathrooms, Margolis Apartments, Chelsea, Massachusetts.

The building is exposed on all sides to the wind, and is located less than 5 km from the airport weather station. Airport weather data records a mean annual wind speed of 6 m/s with up to 26 m/s wind speeds in winter. The winter wind is primarily from the northwest; the wind in spring through fall is from the southwest.

In December, 1992, the building underwent extensive retrofits. New double-pane, low-e windows replaced the old windows throughout the building. A computerized energy management system was installed that allowed for tracking and controlling of the thermostats in the individual apartments. Efficient light bulbs were installed in the individual apartments and in the parking areas. A new sprinkler system was installed throughout the building. The balconies were screened in to prevent the pigeons from roosting. A second phase of retrofit activity a year later involved improvements to the abandoned ventilation system.

Prior to the window retrofit, drafts were a major complaints expressed by the tenants, but since the retrofit, there have been--according to building management--fewer complaints about window drafts. There was mention of the windows being hard to open for some of the residents, both from the latching mechanism and the effort needed to lift the double-hung sash. No problems with condensation on the windows were reported since the retrofit.

The northwest-facing units (weather side) continue to be the hardest units to maintain thermal comfort. Also the second floor units (above the open parking areas) continue to be a problem in cold weather.

## 3.0 Measurements & Analysis

The measurements and analysis that we are reporting here consist of four parts: 1) Air leakage measurements of the apartments measured pre- and post-retrofit, 2) Air flow measurements of the apartments pre-retrofit, 3) Pressures and flows between the apartments and the circulation areas and 4) Computer simulations of the air flows in the building under different weather conditions.

### 3.1 Air Leakage Measurements

We measured the air leakage in nine apartments, before and after the new windows were installed. Figure 5 shows a plot of one of the air leakage measurements. The average pre-retrofit total effective leakage area for the one-bedroom apartments was 241 $cm^2$ and 256 $cm^2$ for the two-bedroom apartments. The post-retrofit total effective leakage area for the one-bedroom apartments was 230 $cm^2$ and 248 $cm^2$ for the two-bedroom apartments (Table 1).

**Table 1: Leakage Areas Pre- and Post-Retrofit**

| **Apartment** | **Leakage Area @ 4 Pascals(a) [cm2]** | |
|---|---|---|
| | pre-retrofit | post-retrofit |
| 301 (2-bdrm) | 228 | 240 |
| 313 (2-bdrm) | 284 | 257 |
| 704 | 173 | 167 |
| 1102 | 280 | - |
| 1107 | 309 | 293 |
| 1211(b) | 180 | 246 |
| 1213 | 238 | 215 |
| 1313(c) | 205 | 278 |

(a) fit to n=0.667
(b) air conditioner in window post-retrofit only
(c) bedroom window not fully closed during post-retrofit test

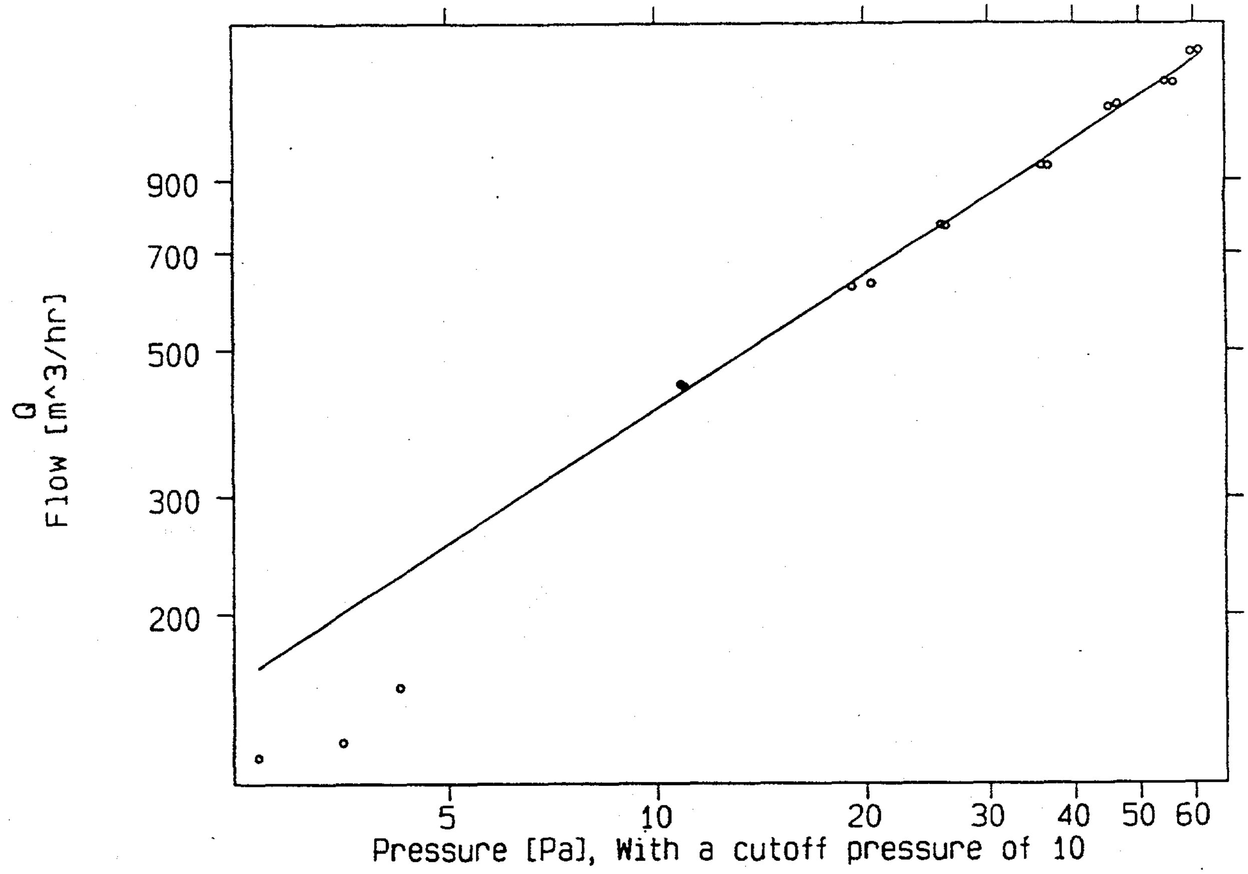

**Figure 5.** Air flow versus pressure from blower door measurements at an apartment on the 12th floor of the Margolis Apartments. The Effective Leakage Area (ELA) was 237 $cm^2$ at 4 pascals and 324 $cm^2$ at 25 pascals.

We found little or no reduction in air leakage due to the new windows, which is surprising given that tenants who had previously complained of drafts were now satisfied. One explanation is that tenants were previously experiencing down drafts at the window due to cold surface temperatures, which no longer occur because of the new double-pane, low-e windows.

We also note that these measurements, both pre- and post-retrofit, were made in very windy conditions--beyond the limits allowed for standard blower-door tests. While this problem is not uncommon in low-rise buildings, it is an even bigger problem in high-rise buildings, where wind speeds are often much higher than for buildings at ground level. Furthermore, the measurement technique being used is based on a reference pressure describing the pressure field around the building. In large buildings, it is very difficult to find a pressure point which acts as the reference pressure for the apartment being investigated. There is also the possibility that the measurement technique itself, i.e., depressurization with a blower door, temporarily seals the windows and distorts the findings.

By way of comparison, Kelley et al. (Kelly 1992) measured the air leakage pre-and post-retrofit in a high-rise apartment in Revere, Massachusetts, a few kilometers north of the Margolis apartment. They found an average pre-retrofit leakage for 17 of the apartments of 904 $m^3/h$ at 50 pascals, and a post-retrofit leakage of 763 $m^3/h$ at 50 Pascals, a reduction of 15%. The comparable flows at Margolis were higher, and showed no reduction after the retrofit, with an average of 1183 $m^3/h$ pre-retrofit and 1214 $m^3/h$ post-retrofit (Table 2).

**Table 2: Air Flow Pre- and Post-Retrofit**

| **Apartment** | **Air Flow @ 50 Pascals(a) [m3/hr]** | |
|---|---|---|
| | pre-retrofit | post-retrofit |
| 301 (2-bdrm) | 1140 | 1204 (+5%) |
| 313 (2-bdrm) | 1416 | 1288 (-10%) |
| 704 | 864 | 838 (-3%) |
| 1102 | 1397 | - |
| 1107 | 1541 | 1469 (-5%) |
| 1211(b) | 901 | 1233 (+37%) |
| 1213 | 1188 | 1076 (-9%) |
| 1313(c) | 1025 | 1394 (-) |

(a) fit to n=0.667
(b) air conditioner in window post-retrofit only
(c) bedroom window not fully closed during post-retrofit test

### 3.2 Air Flow Measurements

Ventilation rates were measured using tracer gas in two apartments, pre-retrofit, in various configurations of exhaust ventilation. With no supply or exhaust ventilation we found typical rates to be about 0.2 ACH (Figure 6).

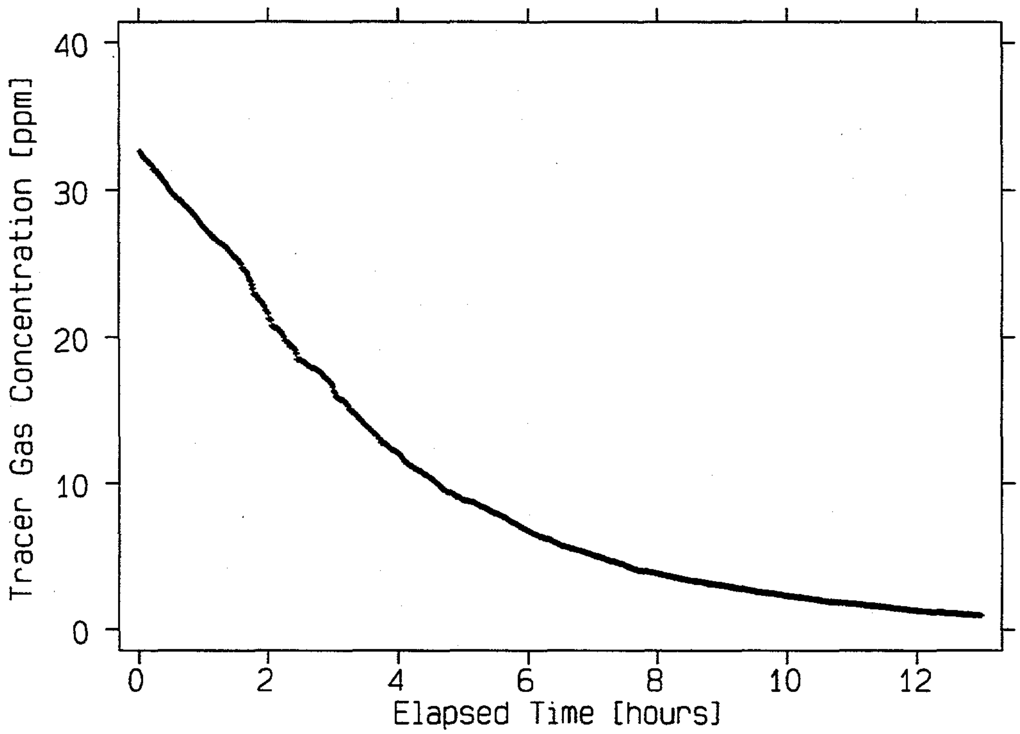

**Figure 6**. Tracer gas decay **without** supply and exhaust fans in operation for a unit on the 12th floor of the Margolis Apartments (June 12, 1992). The decay corresponds to an air exchange rate of 0.2 ACH.

We also measured the leakage from one apartment to another, using tracer gases, and found little communication between units--less than 4% of the total leakage was to adjacent apartments. This was not altogether surprising given the concrete construction of the building.

These ventilation rates are below the recommended 0.35 ACH given in ASHRAE Standard 62 . Operation of the building supply system and the exhaust systems increased the ventilation rate to 0.44 ACH (Figure 7). If the mechanical ventilation systems were operating at their designed flows, the apartment ventilation rates might well meet the ASHRAE standard without excess ventilation.

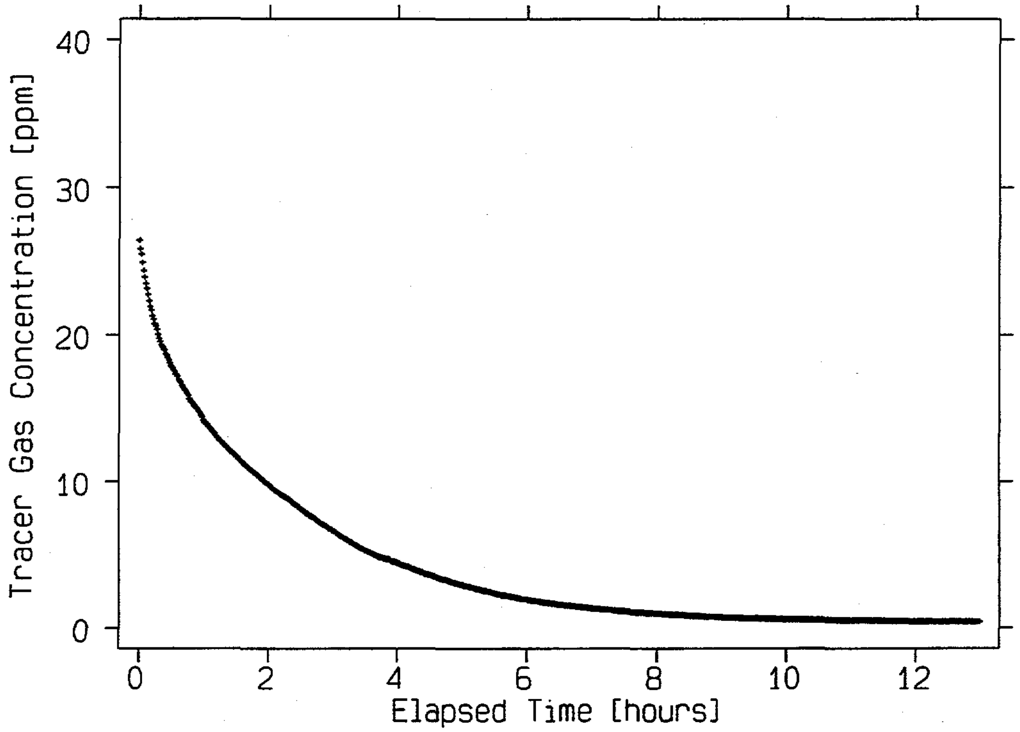

**Figure 7**. Tracer gas decay **with** supply and exhaust fans in operation for a unit on the 12th floor of the Margolis Apartments (June 13, 1992). The decay corresponds to an air exchange rate of 0.4 ACH.

We measured the exhaust air flow from the kitchen hoods and the bathroom vents using a hot-wire anemometer. The filter area of the kitchen hood was divided into 5 sub-areas and an average velocity for each area was determined. From the air velocity, the flows were then calculated. The air velocity was also measured for several locations in the three-slot arrangement of the bathroom exhaust.

The exhaust flows of the seven apartments investigated showed the following characteristics: 1) air flow at the kitchen exhaust register with both the roof exhaust fan and the building supply on, but with the local exhaust fan off, ranged from 50 to 170 cfm, with a mean value of 92 cfm, significantly higher than the design value, (see Figure 8), 2) air flow at the bathroom exhaust register was smaller than the kitchen exhaust flows, and ranged from 40 to 86 cfm, with a mean value of 53 cfm, 3) With the addition of the local exhaust fan operating, kitchen exhaust flows reach values between 170 to 200 cfm (mean = 188 cfm) and, 4) the air flow at the bathroom register with the local bathroom fan operating (together with the roof top exhaust fan) produced 110 to 140 cfm (mean = 122 cfm).

Under normal operating conditions, i.e., the local bathroom and kitchen exhaust off, the total exhaust flow in the apartments would be between 100 and 260 cfm (mean = 145 cfm). The mean air flow supplied to the apartments from the corridor was measured at 22 cfm, so on average, under these weather conditions, the apartment would be drawing in an additional 120 cfm of outside air through the exterior wall and windows. This over-ventilation suggests the need for lowering the roof exhaust fan flow rates.

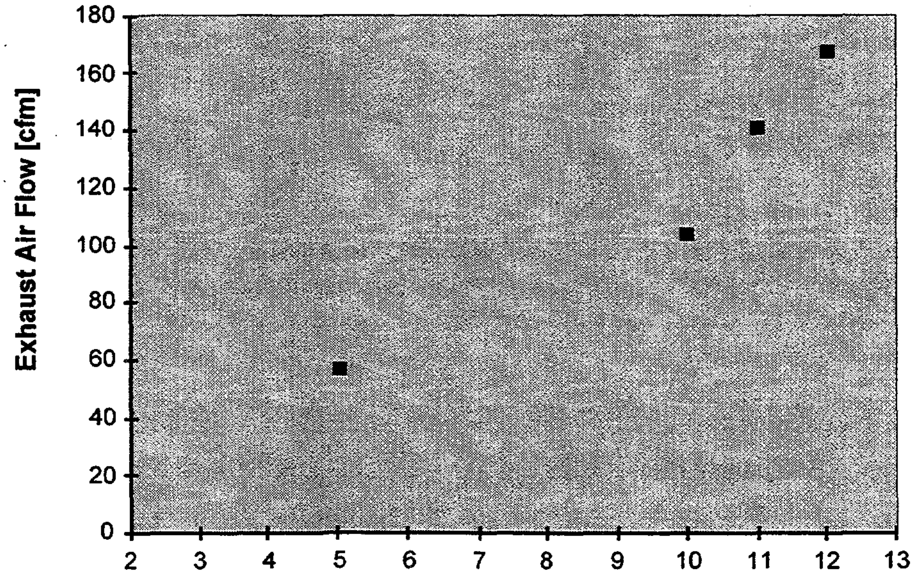

**Figure 8**. Kitchen exhaust air flow with the local exhaust fans off. Measurements were made at the same exhaust shaft at floors 5, 10, 11 and 12.

### 3.3 Temperatures, Pressures and Flows

We measured the temperature of the supply air at the hallway registers for floors 2-13, and they were all in the range of 28-30 $^{O}$C (83-86) $^{O}$F (see Figure 9). These temperatures were higher than the setpoint in the EMCS for the air supply, which is surprising, but in fact it serves as a more efficient strategy by providing air heated with the gas system than the individual electric units in the apartments and, it avoids cold drafts along the floor!

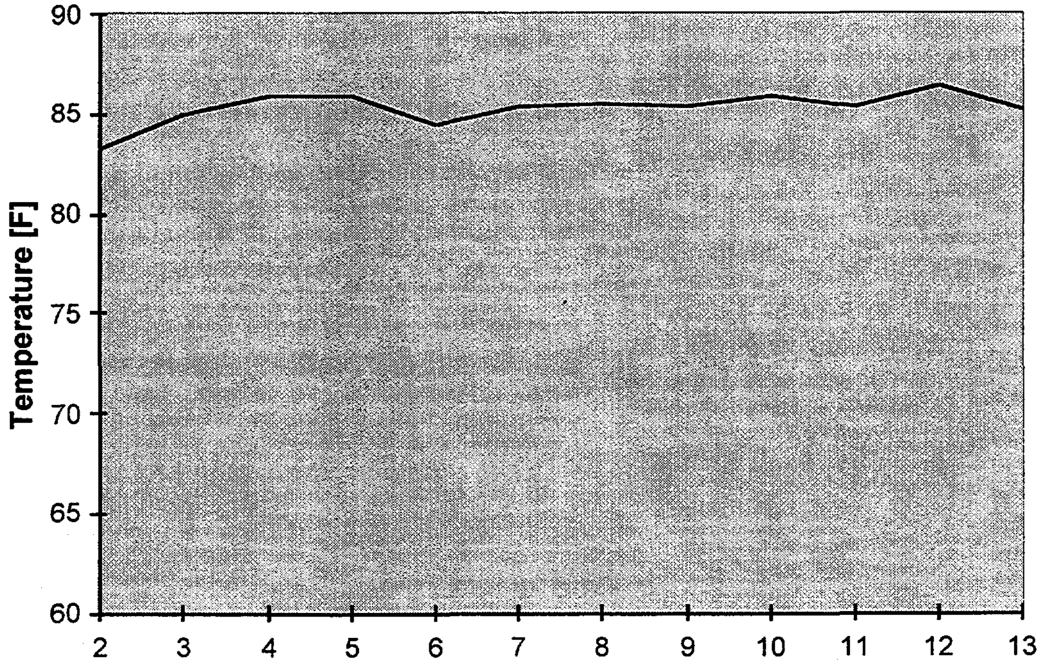

**Figure 9**. Supply air temperature measured at the hallway registers.

We also measured the supply air flows at the hallway registers and they were all within a range of 900-1300 $m^3$/hr (530-760 cfm) per floor, with the average matching the design specification for the supply air flow (Figure 10).

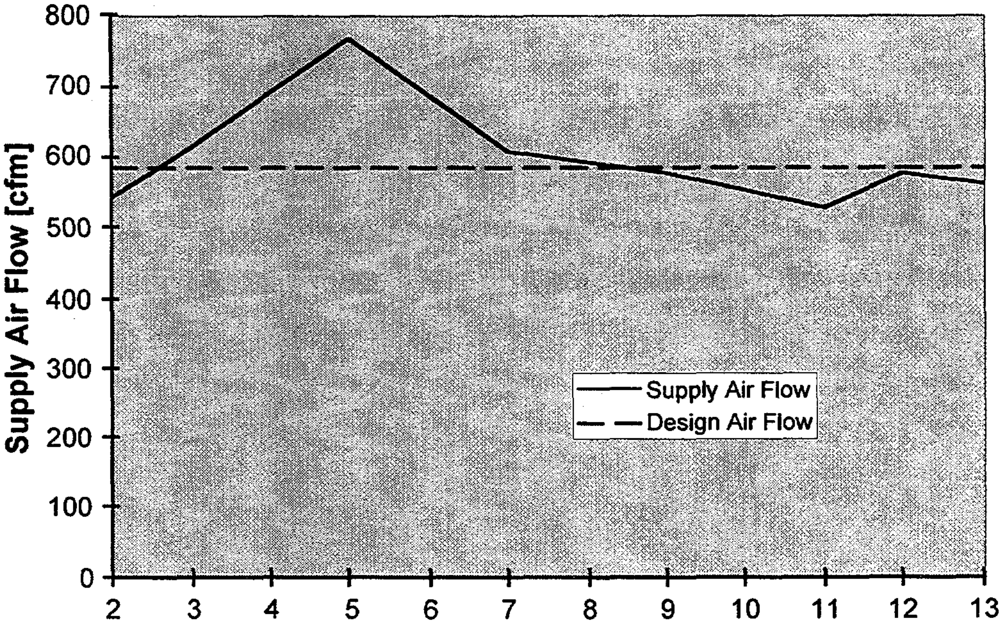

**Figure 10**. Supply air flow measured at the hallway registers.

The air velocity in the elevator shaft was measured at the top of the shaft at the floor of the penthouse elevator room (which has a large opening to the leeward side). The air velocities ranged between 0.7 and 1.5 m/s with both cabs running (regardless of direction) suggesting the air flow is determined more by wind and stack effect than by the movement of the cabs. The air flow at the top of the elevator shaft during the first measurement was out of the shaft, reversing direction later in the day, i.e., down the shaft, when the wind shifted direction from the northwest to the northeast.

Inside the building, the air velocity from the elevator shaft into the corridor ranged from 2 m/s at the 13th floor down to 0.7 m/s at the 3rd floor. The temperature in the elevator was 19 $^{o}$C (66 $^{o}$F) when the outside temperature was 7 $^{o}$C (45 $^{o}$F). The air velocity at the trash chute at the 13th floor, with the door open, was 4 m/s, upwards, another indicator of the stack effect in the building.

The pressures from the stairwells to the hallway follow the expected pattern of positive pressures to the outside above the neutral pressure level (roughly the midpoint of the building) and negative pressures below, with the profiles of both the north and south towers being similar. The pressure range from -4 to +8 pascals is relatively small, due to the relatively mild temperatures outside during the measurement 7 °C (45 °F) and the low wind speeds (Figure 11).

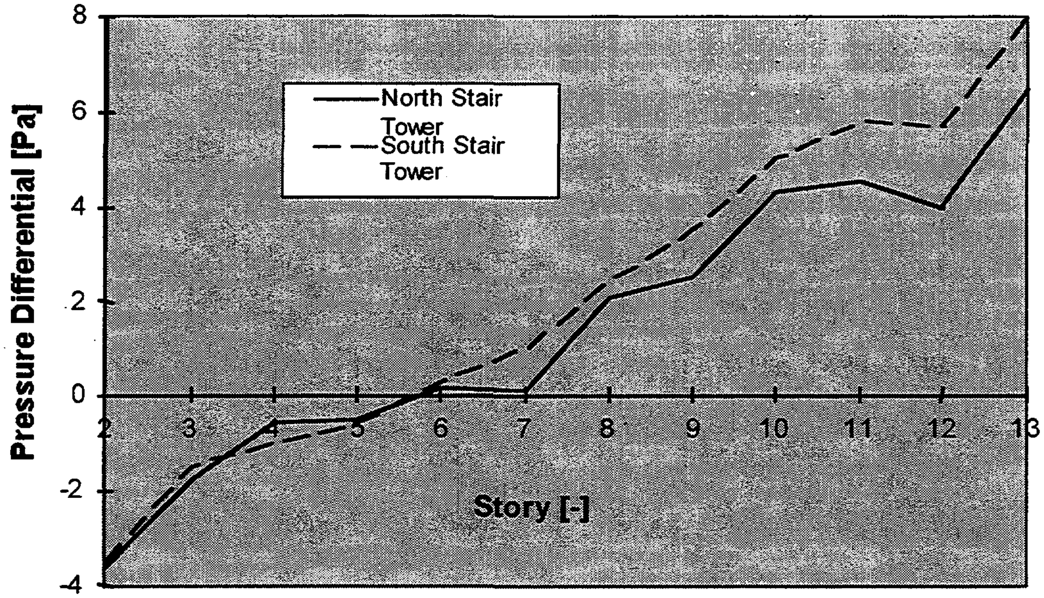

**Figure 11**. Pressure differences between the stair towers and the hallways.

### 3.4 Ventilation Simulations

Based on the measured air leakage data from the building we conducted extensive air flow modeling of the apartments using the multizone air flow model COMIS, a simulation tool, developed at Lawrence Berkeley Laboratory, which calculates air flows based on mass balance calculations for individual zones (Feustel, 1990). To make the simplified model, each floor was divided into four corner zones (one apartment each), one zone describing five apartments on the southeast facade, one zone describing four apartments on the northwest facade, one zone describing the hallway and one zone each for the staircases and the elevatorshaft. The supply shaft and the exhaust shafts were modelled as additional zones. Over one hundred zones were defined in the model (see COMIS input file "CHELSEA.CIF" in the Appendix) with 138 outside pressure points (windpressure distribution) and 565 flow paths were necessary to describe the air flow patterns within the building. (CPU-time for nine different wind velocity / temperature difference combinations is 66 seconds on a SUN SparC ELC computer.) In order to limit the amount of input needed for the simulation model, each apartment was modeled as one zone, assuming the internal doors to be open. To account for the stack effect and the inter-zonal flows between the floors, all 13 floors were modeled.

The results show, that with wind blowing perpendicular to the windward side and no stack effect present, air moves from the windward side facade through the corridors into the leeward side apartments. Under the previous conditions with no ventilation system present, only a small portion of the infiltration air is exhausted through the vertical shafts of the exhaust system. Dampers at the apartment level and on top of each of the shafts restrict the exhaust flow.

When the building is operating without the mechanical ventilation system, the air mass flow distribution for windward side apartments on different floors follows a predictable pattern (Figure 12). With increasing wind speed, the distribution of infiltration becomes more pronounced, showing a minimum at the level of the third floor and a maximum at the 11th floor. The leeward side apartments do not experience any infiltration.

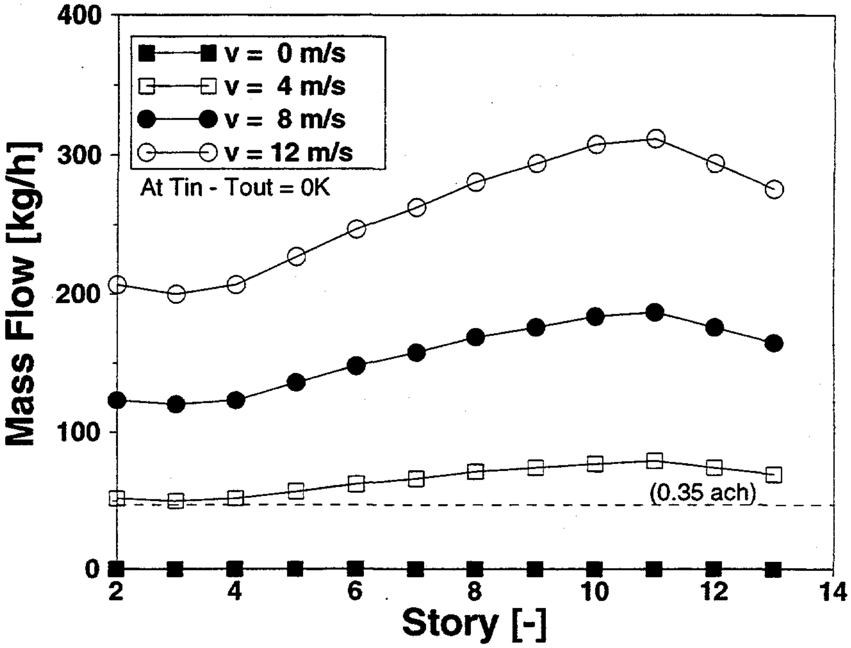

**Figure 12**. Mass air flow into **windward** apartments at different wind speeds, with no inside/outside temperature difference and the mechanical ventilation system **off**.

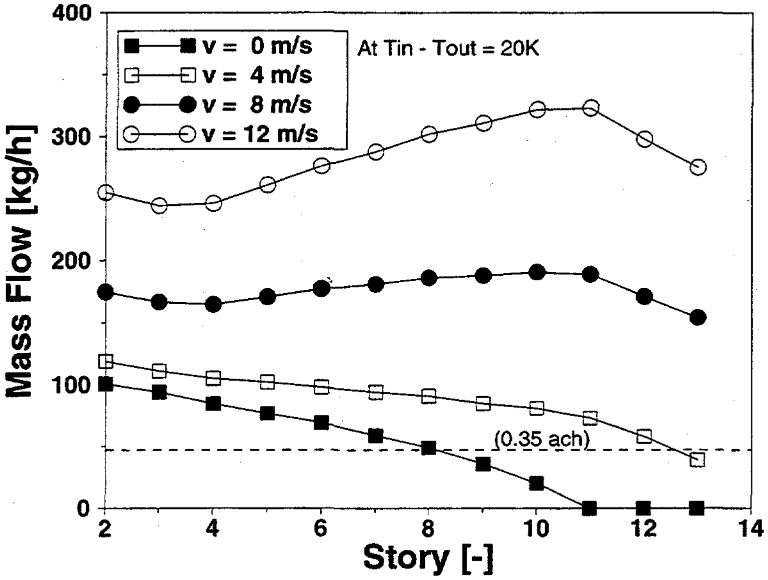

**Figure 13**. Mass air flow into **windward** apartments, at different wind speeds with an inside/outside temperature difference of 20 K and the mechanical ventilation system **off**.

With a larger inside/outside temperature difference of 20 $^{o}$C and zero wind speed, the air flow for the windward apartments decreases with height above ground from 100 kg/h (50 cfm) on the second floor to zero at the level of the 11th floor. With increasing wind speed the air flow curves show a more balanced air flow distribution until the velocity driven air flows override the stack effect (Figure 13). As the pressures forcing the air flow can be added, the air flows for any given wind speed are higher if stack pressure is present.

The air flows for the leeward side is shown in Figure 14. With increasing wind speed the air flow entering the apartments through the outside wall is getting smaller. The zero wind speed curve is the same for the windward side and the leeward side. The top floors do not experience any infiltration. Higher wind speeds cause higher negative pressures on the facade, which lower the level for the neutral pressure. At wind speeds of 12 m/s no infiltration occurs at the apartments facing the leeward side.

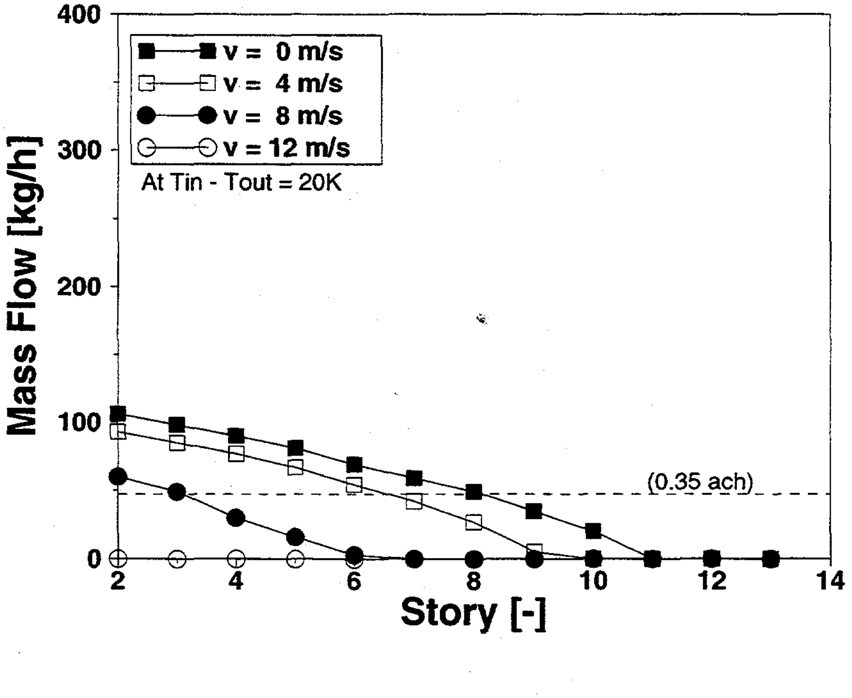

**Figure 14**. Mass air flow into **leeward** apartments, at different wind speeds with an inside/outside temperature difference of 20 K and the mechanical ventilation system **off**.

Air flows into the apartments are slightly higher when the ventilation system is in operation. Figure 15 shows the air flows entering the apartments located on the windward side through the facade for different wind speeds when no stack effect is present. At low wind conditions, infiltration is almost independent of the height above ground. With higher wind speeds, we see that the infiltration flows follow the wind pressure profile.

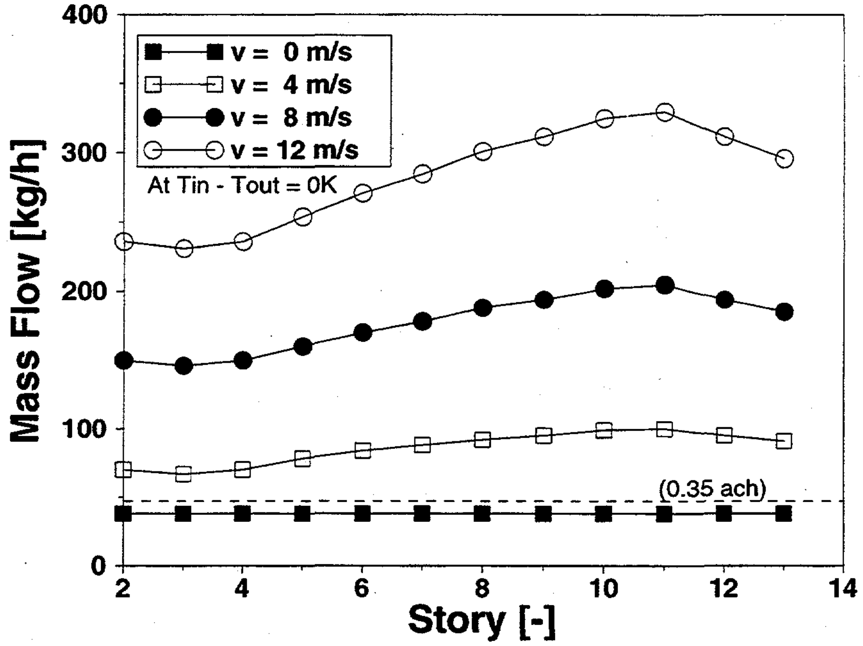

**Figure 15**. Mass air flow into **windward** apartments at different wind speeds, with no inside/outside temperature difference and the mechanical ventilation system **on**.

The infiltration for the leeward side apartments is quite different (see Fig. 16). For the case of no wind and no inside/outside temperature difference, approximately 75 kg/h are sucked by the exhaust system into the apartment through the exterior building components. With increasing wind speeds, the infiltration is reduced. At wind speeds of 4 m/s, approximately 0.35 ACH are still reached, but with higher wind speeds, the infiltration rate is further reduced, until no outside air enters the apartments when the wind velocity exceeds 12 m/s.

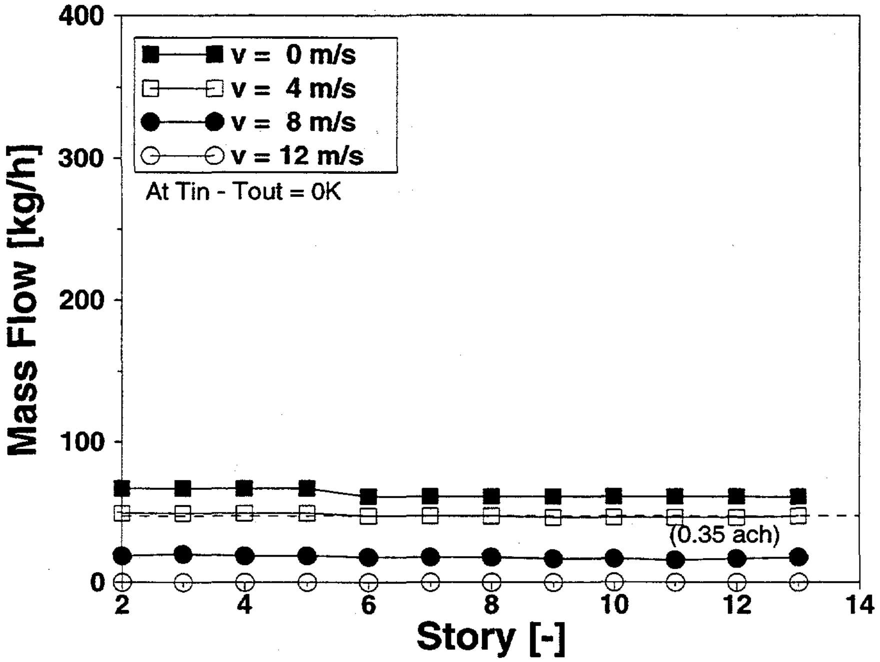

**Figure 16**. Mass air flow into **leeward** apartments at different wind speeds, with no inside/outside temperature difference and the mechanical ventilation system **on**.

The ventilation system is designed to provide the necessary “fresh” air by means of supplying the air to the corridor. The direction of the air flow through the doorway of the apartment determines whether the supplied air is entering the apartments. For the two higher wind speeds, the air flow passing through the doorways are shown for the apartments on both sides of the corridor (Figure 17). We see, that at higher wind speeds the windward side apartments do not receive any of the air supplied to the corridor. At lower wind speeds, the windward side apartments located on the lower floors participate slightly in the air exchange provided by the supply system. This means, that at lower wind speeds about all the air entering through the facade is being exhausted directly into the vertical exhaust shafts. At higher wind speeds, air from these apartments is forced into the corridor.

All leeward side apartments receive between 50 and 75 kg/h air from the corridor (see Figure 17). With higher wind speeds, the amount of air entereing from the corridor increases, however, the air flow being supplied to the corridor via the windward side apartments is much bigger than the air entering the leeward side apartments. The excess air is leaving the corridor through the elevator shaft. The pressure difference between the corridor and the air intake on the roof could significantly reduce the supply air flow to the corridors.

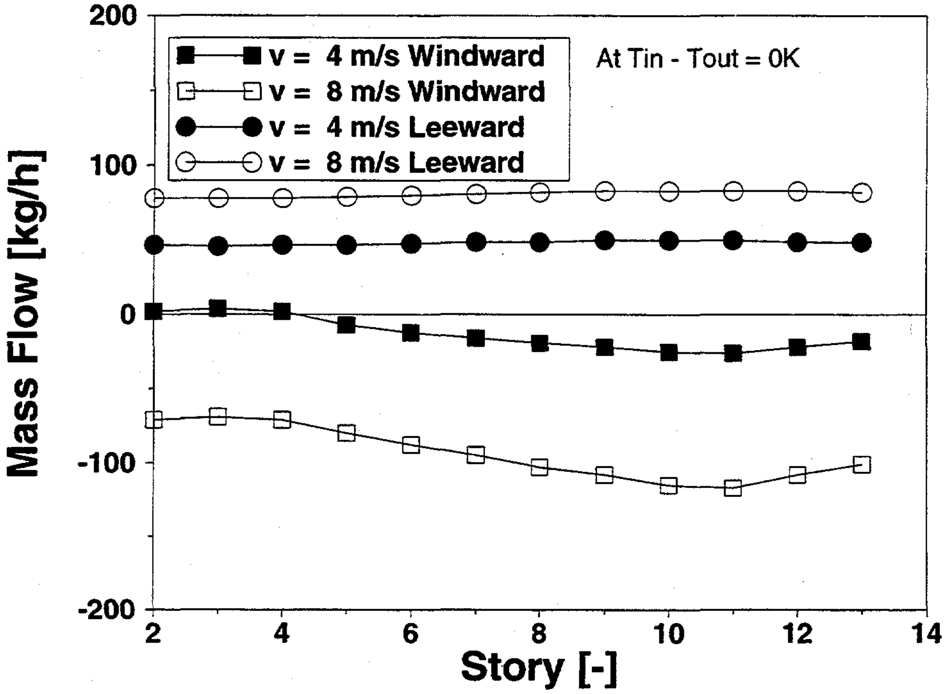

**Figure 17**. Mass air flow between the apartments and the corridor at different wind speeds and no inside/outside temperature difference, for all apartments and with the mechanical ventilation system on.

With larger temperature differences between inside and outside present (winter case), the infiltration flows for the lower windward side apartments increase significantly. As a consequence, flows from windward side apartments to the corridor will increase for the lower storeys (see Figure 18). Due to the stack effect, even leeward side apartments on floors 2 and 3 contribute to the excess flow of the corridors. Higher up in the building, leeward side apartments receive air from the corridor while windward side apartments exhaust air into the corridor. With increasing temperature difference, the stack effect is amplified.

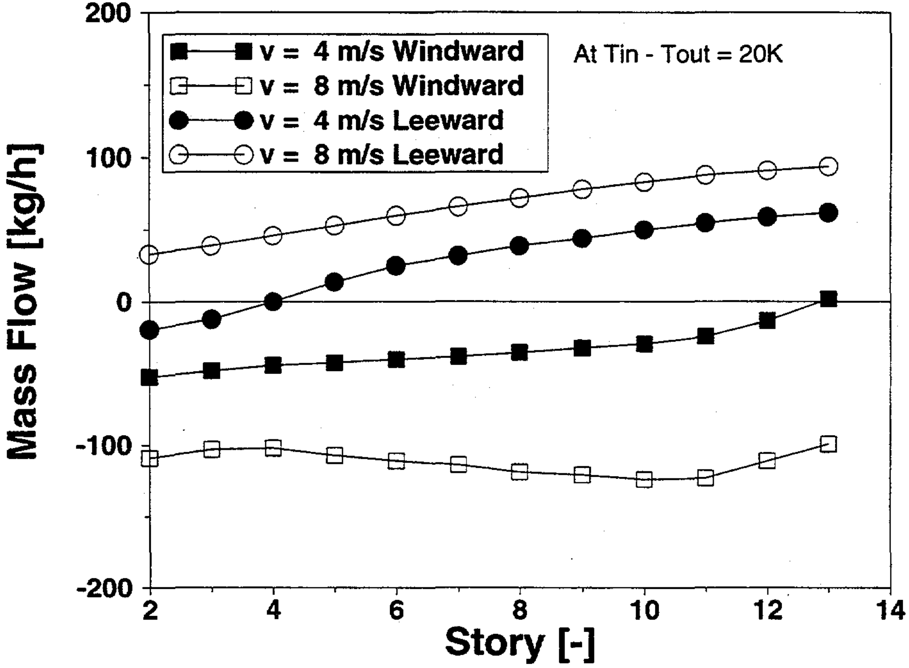

**Figure 18**. Mass air flow between the apartments and the corridor at different wind speeds and an inside/outside temperature difference of 20 K, for all apartments and with the mechanical ventilation system on.

With the mechanical system operating, the apartments on the leeward side have significantly higher ventilation rates than the apartments on the windward side, particularly in the case of high wind speeds. When the wind is parallel to the building, the mechanical ventilation system is needed in order to ensure proper ventilation to the apartments.

## 4.0 Conclusions

In any study of a building as complex as a highrise apartment it is important to validate the findings using as many techniques as possible. In the case of the Margolis Apartments we have been fortunate to have different data sources: leakage measurements, pressure tests and air infiltration measurements which have all been used to validate the model. Because comparisons between the model and measurement data agree well in several areas, such as similar directions and magnitude of pressure differences across apartment doors and stairwell doors, we have a high degree of confidence in the simulation results.

Based on our analysis of the air flow simulations we see that the ventilation to the individual units varies considerably. With the mechanical ventilation system disabled (pre-retrofit case), units at the lower level of the building had adequate ventilation only on days with high temperature differences, while units on higher floors had no ventilation at all. Units facing the windward side were over-ventilated when the building experienced wind directions between west and north. At the same time, leeward side upper apartments would not experience any fresh air--air flows would enter the apartments from the corridor and exit through the exhaust shafts and the cracks in the facade. Even with the mechanical ventilation system operating, we found wide variation in the air flows to the individual apartments.

A fundamental issue here is the design question of how to best supply ventilation to individual apartments in a highrise building. Using the corridor as the supply route has several challenges, including the control of the temperature of the supply air, the temperature of the corridor, the opening from the corridor to the apartment, tenant comfort and the balance between supply and apartment exhaust.

A major conclusion from our measurements and simulations is that each apartment has to be supplied with ventilation air directly. Pressure drops of the system have to be high enough to overcome natural forces to be able to ensure an even distribution of ventilation air. If ventilation air is supplied directly to the individual apartments, the apartments should be uncoupled from the rest of the building by tight apartment doors. This condition not only decreases the impact of natural forces on the distribution of ventilation air, but also reduces the disturbance to tenants of odors or noise from other apartments. In winter, supply air has to be preheated to avoid unpleasant cold drafts. Supply air provided by vents in the envelope should either be preheated by heating elements in the vent itself, or be supplied adjacent to heating sources. Ducted supply air should be preheated in the central unit.

On the exhaust side, studies have shown that when apartment occupants have local control over bathroom and kitchen exhaust, they use them less than one hour per day, if at all (Shapiro-Baruch, 1993), which makes it difficult to size the supply ventilation system. Continuous exhaust ventilation, however, presents the possibility of over ventilation and unnecessary use of energy.

Efforts to improve the energy efficiency of high-rise apartment buildings have been frustrated because of the lack of knowledge on air flows for individual apartments. Ventilation rates for individual apartments vary greatly due to height, orientation, and wind speed and outdoor temperature. Any recommendations for reducing air leakage will have to take these variables into account, so that efforts to tighten the shell for energy efficiency do not create health and comfort problems for the residents.

## 5.0 Acknowledgments

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# APPENDIX:

## Margolis Apartments Input File for the *COMIS* Simulation Program

```
&-CIF                        1
  _______________________
 |COMIS Input File       |
 |_______________________|
help.cif


&-PR-IDENTification          2
  ________________
 |1.|Problemname  |
 |__|             |
 |________________|
 Boston/Chelsea Housing for the Elderly
 All Input in kg/h; Dimensions in *SET-File must be in kg/s!
 Kitchen- and Bathroom-Shaft were combined. No Fans at the
 Floor-Level present; only on the Roof. Resistance for the
 Duct is distributed between Dampers in the Flats and Dampers
 adjacent to the Fans. Only Corner-Apartments are modelled;
 middle Apartments are combined (East- and West-Apartments
 are treated separately).
 LINK heights are adjusted!


  ________________
 |2.|Versionname  |
 |__|             |
 |________________|
 June 18, 1992


&-PR-OUTPut options          3
  _____________________________________________________________
 | Output Option Keywords:  One keyword per line only          |
 |                          Keywords may be preceded by NO     |
 |_____________________________________________________________|
 | VENT:ilation             POL:utant              HEAT:flow   |
 | CONC:entrations                                             |
 |                          INPUT echo                         |
 |                          DEFAULT echo                       |
 |                          SET echo                           |
 | SCHED:time<time>                                            |
 | START:time<time>[CONT|REUSE]    STOP:time<time>[KEEP]       |
 |_____________________________________________________________|
 | Graphical Output Options: Define data to be Stored:         |
 | PZ-S {Zones} = Pressure    | FL-S {Links}   = Flow          |
 | TZ-S {Zones} = Temperature| TL-S {Links}   = Temperature   |
 | MZ-S {Zones} = Moisture    | SL-S {Links}   = Status        |
 | FZ-S {Zones} = Flow        | HU-G           = Humidity      |
 | VE-G         = Velocity    | TE-G           = Air Temp.     |
 | Cn-S {Zones} = Concentr.   | Pn-S {Zones}   = Poll. Str.    |
 | Sn-S {Zones} = Poll. Sink  | WP-S {Points} = Windpr.        |
 |   for Gas n (1<= n <=5)    |                                |
 |                                                             |
 | To define graphs:  replace -S with -T (Table entry)         |
 |_____________________________________________________________|
 VENTILATION
 PZ-S 1
                 STARTtime 1992jan01_0:00
                 STOPTIME  1992jan01_10:00
```

```
&-PR-CONTrol parameters    4                 --- OPTIONAL DATASE CTION ---

  _____________________________________________________________________
 |1.| Under |     T  o  l  e  r  a  n  c  e  s   |Start  |Link Flow   |
 |__| Relax-|____________________________________|Number |Pressure    |
 |    ation | absolute  | Relative |CORR*JAC(i,i)|of Ite-|Laminar Flow|
 |    Factor|  EpsFA    |  EpsFR   | EpsCJ       |rations|DifLim      |
 |    [-]   |  [kg/s]   |  [-]     |  [kg/s]     |  [-]  |   [Pa]     |
 |__________|___________|__________|_____________|_______|____________|
 1.          1.E-06      1.E-05     0.            1       1.E-12

 ______________________________________________________________________
 |2.|   use old   |No Pressure   | Solver Selector           |Max      |
 |__|  Pressures  |Initialization|                           |Number of|
 |               |              |0=optimum relax COMIS      |Iterations
 |0=Zero         |0=Lin.initial.|1=Newton (with given Relax)|allowed  |
 |  Pressures    |1=No initial. |2=Newton Steffensen        |         |
 |1=use          |              |3=Walton Steffensen        |         |
 |  Previous     |              |4=One avg. Steffensen      |         |
 |               |              |5=Walton 2 fixed relax.fact|         |
 | UseOPz        |NoInit        |        SlvSel             | Miter   |
 |     [-]       |     [-]      |          [-]              |  [-]    |
 |_______________|______________|___________________________|_________|
 1                0              5                          50


&-NET-AIR flow components
# Allowed prefixes are: *CR  *FA *DS *DF *F1 *F2 *F3 *F4 *WI *TD
#                       |     |  |    |  |____________|   |  |
#                       crack |  duct |  flow-controllers |  testdata points
#                             fan     duct-fitting        window(openable)
# keep the KEYWORDs &-CR,...,&-TD in this part &-NET-AIR

&-CR       CRACK

  _______________________________________________________
 |1.|   Cs     |Exp n   | Lenght  |   Wall Properties    |
 |__|          |        |         | Thickness  | U-Value |
 |   (kg/s@1Pa)|  (-)   |  [m]    |    [m]     |[W/m2  K]|
 |_____________|________|_________|____________|_________|

  __________________________________________________________
 |2.|Filter 1   | Filter 2 | Filter 3 | Filter 4 | Filter 5 |
 |__|   (-)     |   [-]    |   [-]    |   [-]    |   [-]    |
 |______________|__________|__________|__________|__________|

*CRw1          Windows (individual)
10.             0.67
0

*CRw2          Two Windows (units 001 & 013 for floors 2-5)
20             0.67
0

*CRwse         Sum of windows east facade
50.            0.67
0

*CRwsw         Sum of windows west facade
40.            0.67
0

*CRd1          Entry door to individual flat
10.            0.67
0
```

```
*CRdse  Sum of entry doors east facade
50.             0.67
0

*CRdsw  Sum of entry doors west facade
40.             0.67
0

*CRb1           Balcony doors (individual)
40.             0.67
0

*CRbse          Sum of balcony doors east facade
200.             0.67
0

*CRbsw          Sum of balcony doors west facade
160.             0.67
0

*CRsd           Staircase door
35.             0.67
0

*CRed           Elevator and lobby door
100.             0.67
0

*CRfd           Fire door in corridor
0.             0.67
0

*CRev           Elevator vent (Penthouse)
2000.             0.67
0

*CRda           Dampers for kitchen or bathroom exhaust
12.00             0.5
#4.17            0.50
0

*CRdsae         two times Sum of dampers for kitchen or bathroom east facade
120.             0.5
#42.0            0.50
0

*CRdsaw         two times Sum of dampers for kitchen or bathrooms west facade
106.             0.5
#33.6            0.50
0

*CRdr1          Exhaust damper for kitchen or bathroom on the roof
365.            0.5
#100.            0.50
0

*CRdre          Sum of exhaust dampers on the roof east facade
1852.            0.50
#500.            0.50
0

*CRdrw          Sum of exhaust dampers on the roof west facade
1460.            0.50
#400.            0.50
```

```
0

*CRdsr          Supply air damper in central system
1806.          0.50
0

*CRdsc          Supply air damper in corridor
150.           0.5
0

*CRho           leakage horizontal
0.              0.67
0

*CRve           leakage vertical
0.              0.67
0

*CRsvw          vertical leakage west
0.              0.67
0

*CRsve          vertical leakage east
0.              0.67
0

*CRfan
100.            0.5
0


&-FA       FAN
# line1= flag....  #line2=Pminimum....   #line3=C0.....
# line4 - line7=datapairs,last line is always the filter line
  ______________________________________________________________
 |1.|# Flag: 1=use Polynomial C0,..C5                           |
 |__|        2=use Data pairs to calculate C0,..Cni             |
 |  ____________________________________________________________|
 | Flag|Exp Polynom.|RhoI     | NfI     |    Cm          | Exp n |
 |(-)  |(-)         |(kg/m3)  |[rpm]    |[kg/s@1Pa]      |[-]    |
 |_____|____________|_________|_________|________________|_______|
  ________________________________________
 |2.| Pmin    |  Pmax    |Slope     | Intercept |
 |__| (Pa)    |  (Pa)    |(m3/s/Pa) |(m3/s)     |
 |__________|__________|__________|___________|
  __________________________________________________________________
 |3.|C0      |C1       |C2        |C3        |C4        |C5        |
 |__|(m3/s)  |[m3/s/Pa]|[../Pa2 ] |[../Pa3  ]|[../Pa4 ] |[../Pa5]  |
 |_________|_________|__________|__________|__________|__________|
  ___________________________________________________________________________
 |4.  |Fan Curve Pressure Rise vs FlowRate   maximum 4 Lines                  |
 |__  | Data Pairs    minimum 3 Pairs,     maximum 12 Pairs                   |
 |(Pa)|      (m3/s)      |(Pa)       | (m3/s)      |(Pa)        |(m3/s)       |
 |____|__________________|___________|_____________|____________|_____________|
  ________________________________________________________________
 |8.|Filter 1     | Filter 2 | Filter 3 | Filter 4 | Filter 5 |
 |__|  (-)        |    [-]   |    [-]   |    [-]   |    [-]   |
 |______________|__________|__________|__________|__________|
```

```
*FAsup               Supply Fan
2      4              1.2       1    0.1             0.5
 0.00000E+00  0.17474E+03 -0.91624E+02  0.16011E+05
 0.16011E+05 -0.69381E+01 -0.15266E+00  0.32635E-02 -0.29547E-04  0.00000E+00
0.   16000      30       15800    50       15400

80      15000   125      11900    160      5000
0

*FAr1                Rooftop  Exhaust Fan (Double Value)
2      4              1.2       1     0.1            0.5
 0.00000E+00  0.17476E+03 -0.18844E+02  0.32932E+04
 0.32932E+04 -0.14421E+01 -0.30499E-01  0.66098E-03 -0.60439E-05  0.00000E+00
0       3291    30       3250     50       3168
80      3086    125      2448     160      1029
0

*FArw                Sum of Fans for the West
2      4              1.2       1     0.1            0.5
 0.00000E+00  0.17475E+03 -0.74908E+02  0.13090E+05
 0.13090E+05 -0.56936E+01 -0.12458E+00  0.26680E-02 -0.24159E-04  0.00000E+00
0       13081   30       12917    50       12590
80      12263   125      9729     160      4088
0

*FAre                 Sum of Fans for the East
2      4              1.2       1     0.1            0.5
 0.00000E+00  0.17475E+03 -0.94240E+02  0.16468E+05
 0.16468E+05 -0.71717E+01 -0.15569E+00  0.33435E-02 -0.30351E-04  0.00000E+00
0       16457   30       16251    50       15840
80      15429   125      12240    160      5143
0


&-NET-ZONEs                        18
  ____________________________________________________________________
 |Zone| Name              | Temp   |Ref.   |Vol   |Abs.   | Schedule  |
 | No |                   |        | Height|      | Hum   |  Name     |
 | (-)|[-]                |  [oC]  |  [m]  | [m3] |[gr/kg]| [T./H..]  |
 |____|___________________|________|_______|______|_______|___________|
 1      0202              20.       3.
 2      0201              20.       3.
 3      0212              20.       3.
 4      0213              20.       3.
 5      0204              20.       3.
 6      0207              20.       3.
 7      0214              20.       3.
 8      0302              20.       6.
 9      0301              20.       6.
 10     0312              20.       6.
 11     0313              20.       6.
 12     0304              20.       6.
 13     0307              20.       6.
 14     0314              20.       6.
 15     0402              20.       9.
 16     0401              20.       9.
 17     0412              20.       9.
 18     0413              20.       9.
 19     0404              20.       9.
 20     0407              20.       9.
 21     0414              20.       9.
 22     0502              20.       12.
 23     0501              20.       12.
 24     0512              20.       12.
```

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 25    0513          20.      12.
 26    0504          20.      12.
 27    0507          20.      12.
 28    0514          20.      12.
 29    0602          20.      15.
 30    0601          20.      15.
 31    0612          20.      15.
 32    0613          20.      15.
 33    0604          20.      15.
 34    0607          20.      15.
 35    0614          20.      15.
 36    0702          20.      18.
 37    0701          20.      18.
 38    0712          20.      18.
 39    0713          20.      18.
 40    0704          20.      18.
 41    0707          20.      18.
 42    0714          20.      18.
 43    0802          20.      21.
 44    0801          20.      21.
 45    0812          20.      21.
 46    0813          20.      21.
 47    0804          20.      21.
 48    0807          20.      21.
 49    0814          20.      21.
 50    0902          20.      24.
 51    0901          20.      24.
 52    0912          20.      24.
 53    0913          20.      24.
 54    0904          20.      24.
 55    0907          20.      24.
 56    0914          20.      24.
 57    1002          20.      27.
 58    1001          20.      27.
 59    1012          20.      27.
 60    1013          20.      27.
 61    1004          20.      27.
 62    1007          20.      27.
 63    1014          20.      27.
 64    1102          20.      30.
 65    1101          20.      30.
 66    1112          20.      30.
 67    1113          20.      30.
 68    1104          20.      30.
 69    1107          20.      30.
 70    1114          20.      30.
 71    1202          20.      33.
 72    1201          20.      33.
 73    1212          20.      33.
 74    1213          20.      33.
 75    1204          20.      33.
 76    1207          20.      33.
 77    1214          20.      33.
 78    1302          20.      36.
 79    1301          20.      36.
 80    1312          20.      36.
 81    1313          20.      36.
 82    1304          20.      36.
 83    1307          20.      36.
 84    1314          20.      36.
 85    staircase     20.      0.
 86    staircase     20.      0.
 87    elevator      20.      0.
 88    shaft02       20.      0.
```

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 89    shaft01        20.      0.
 90    shaft12        20.      0.
 91    shaft13        20.      0.
 92    shaft04        20.      0.
 93    shaft07        20.      0.
 94    shaftsupp      20.      0.
 95    lobby          20.      0.
 96    damper02       20.      41.
 97    damper01       20.      41.
 98    damper12       20.      41.
 99    damper13       20.      41.
 100   damper04       20.      41.
 101   damper07       20.      41.
 102   dapersup       20.      41.

&-NET-EXTernal node data          21         --- OPTIONAL DATASECTION ---
  _______________________________________________________________________
 |External Node No  |  Facade Elem No   |  Outside Conc Factor|
 |              (-) |     (-)           |  [-]                |
 |__________________|___________________|_____________________|
 1                   1                  0.
 2                   2                  0.
 3                   3                  0.
 4                   4                  0.
 5                   5                  0.
 6                   6                  0.
 7                   7                  0.
 8                   8                  0.
 9                   9                  0.
 10                  10                 0.
 11                  11                 0.
 12                  12                 0.
 13                  13                 0.
 14                  14                 0.
 15                  15                 0.
 16                  16                 0.
 17                  17                 0.
 18                  18                 0.
 19                  19                 0.
 20                  20                 0.
 21                  21                 0.
 22                  22                 0.
 23                  23                 0.
 24                  24                 0.
 25                  25                 0.
 26                  26                 0.
 27                  27                 0.
 28                  28                 0.
 29                  29                 0.
 30                  30                 0.
 31                  31                 0.
 32                  32                 0.
 33                  33                 0.
 34                  34                 0.
 35                  35                 0.
 36                  36                 0.
 37                  37                 0.
 38                  38                 0.
 39                  39                 0.
 40                  40                 0.
 41                  41                 0.
 42                  42                 0.
 43                  43                 0.
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 44                  44                  0.
 45                  45                  0.
 46                  46                  0.
 47                  47                  0.
 48                  48                  0.
 49                  49                  0.
 50                  50                  0.
 51                  51                  0.
 52                  52                  0.
 53                  53                  0.
 54                  54                  0.
 55                  55                  0.
 56                  56                  0.
 57                  57                  0.
 58                  58                  0.
 59                  59                  0.
 60                  60                  0.
 61                  61                  0.
 62                  62                  0.
 63                  63                  0.
 64                  64                  0.
 65                  65                  0.
 66                  66                  0.
 67                  67                  0.
 68                  68                  0.
 69                  69                  0.
 70                  70                  0.
 71                  71                  0.
 72                  72                  0.
 73                  73                  0.
 74                  74                  0.
 75                  75                  0.
 76                  76                  0.
 77                  77                  0.
 78                  78                  0.
 79                  79                  0.
 80                  80                  0.
 81                  81                  0.
 82                  82                  0.
 83                  83                  0.
 84                  84                  0.
 85                  85                  0.
 86                  86                  0.
 87                  87                  0.
 88                  88                  0.
 89                  89                  0.
 90                  90                  0.
 91                  91                  0.
 92                  92                  0.
 93                  93                  0.
 94                  94                  0.
 95                  95                  0.
 96                  96                  0.
 97                  97                  0.
 98                  98                  0.
 99                  99                  0.
 100                 100                 0.
 101                 101                 0.
 102                 102                 0.
 103                 103                 0.
 104                 104                 0.
 105                 105                 0.
 106                 106                 0.
 107                 107                 0.
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 108                     108                    0.
 109                     109                    0.
 110                     110                    0.
 111                     111                    0.
 112                     112                    0.
 113                     113                    0.
 114                     114                    0.
 115                     115                    0.
 116                     116                    0.
 117                     117                    0.
 118                     118                    0.
 119                     119                    0.
 120                     120                    0.
 121                     121                    0.
 122                     122                    0.
 123                     123                    0.
 124                     124                    0.
 125                     125                    0.
 126                     126                    0.
 127                     127                    0.
 128                     128                    0.
 129                     129                    0.
 130                     130                    0.
 131                     131                    0.
 132                     132                    0.
 133                     133                    0.
 134                     134                    0.
 135                     135                    0.
 136                     136                    0.
 137                     137                    0.
 138                     138                    0.

&-NET-LINks                             22
  ___________________________________________   _____________________________
 |Link|Type | Zone No  |  Height  |  Own |Act.|3Dflow|Schedule Name(5char.)|
 |    |     |__________|__________|      |    |  or  |_____________________|
 |    |     |     |    |     |    |      |    |      |T-Junct.  Ref.Link   |
 | No |Name |From |To  |From |To  |Height|Val.|Press |  No    |  Angle     |
 |(-) |(-)  |(-)  |(-) |[m]  |[m] | [m]  |[-] | [Pa] |  [-]   |  [deg]     |
 |____|_____|_____|____|_____|____|______|____|______|________|____________|
#       stair-case 1 (south-west)
1       CRsd   -11   85    1.    1.
2       CRsd   -15   85    1.    1.
3       CRw1   -22   85    3.    3.
4       CRw1   -32   85    6.    6.
5       CRw1   -42   85    9.    9.
6       CRw1   -52   85    12.   12.
7       CRw1   -62   85    15.   15.
8       CRw1   -72   85    18.   18.
9       CRw1   -82   85    21.   21.
10      CRw1   -92   85    24.   24.
11      CRw1   -102  85    27.   27.
12      CRw1   -112  85    30.   30.
13      CRw1   -122  85    33.   33.
14      CRw1   -132  85    36.   36.
15      CRsd   -135  85    41.   41.
#       stair-case 2 (north-east)
21      CRsd   -11   86    1.    1.
22      CRsd   -15   86    1.    1.
23      CRw1   -24   86    3.    3.
24      CRw1   -34   86    6.    6.
25      CRw1   -44   86    9.    9.
26      CRw1   -54   86    12.   12.
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 27     CRw1  -64  86    15.  15.
 28     CRw1  -74  86    18.  18.
 29     CRw1  -84  86    21.  21.
 30     CRw1  -94  86    24.  24.
 31     CRw1  -104 86    27.  27.
 32     CRw1  -114 86    30.  30.
 33     CRw1  -124 86    33.  33.
 34     CRw1  -134 86    36.  36.
 35     CRsd  -131 86    41.  41.
 #       stair-case 1 and 2  to floors
 50     CRsd  85   7     4.   1.
 51     CRsd  86   7     4.   1.
 52     CRsd  85   14    7.   1.
 53     CRsd  86   14    7.   1.
 54     CRsd  85   21    10.  1.
 55     CRsd  86   21    10.  1.
 56     CRsd  85   28    13.  1.
 57     CRsd  86   28    13.  1.
 58     CRsd  85   35    16.  1.
 59     CRsd  86   35    16.  1.
 60     CRsd  85   42    19.  1.
 61     CRsd  86   42    19.  1.
 62     CRsd  85   49    22.  1.
 63     CRsd  86   49    22.  1.
 64     CRsd  85   56    25.  1.
 65     CRsd  86   56    25.  1.
 66     CRsd  85   63    28.  1.
 67     CRsd  86   63    28.  1.
 68     CRsd  85   70    31.  1.
 69     CRsd  86   70    31.  1.
 70     CRsd  85   77    34.  1.
 71     CRsd  86   77    34.  1.
 72     CRsd  85   84    37.  1.
 73     CRsd  86   84    37.  1.
 #       lobby (ground-floor)
 81     CRsd  -11  95    1.   1.
 82     CRsd  -15  95    1.   1.
 83     CRsd  -17  95    1.   1.
 84     CRsd  -17  95    1.   1.
 #       elevator
 111    CRed  87   95    1.   1.
 112    CRed  87   7     4.   1.
 113    CRed  87   14    7.   1.
 114    CRed  87   21    10.  1.
 115    CRed  87   28    13.  1.
 116    CRed  87   35    16.  1.
 117    CRed  87   42    19.  1.
 118    CRed  87   49    22.  1.
 119    CRed  87   56    25.  1.
 120    CRed  87   63    28.  1.
 121    CRed  87   70    31.  1.
 122    CRed  87   77    34.  1.
 123    CRed  87   84    37.  1.
 124    CRsd  87   -131 41.  41.
 125    CRev  87   -135 43.  43.
 #       supply air shaft
 150    CRdsc 94   7     6.   3.
 152    CRdsc 94   14    9.   3.
 154    CRdsc 94   21    12.  3.
 156    CRdsc 94   28    15.  3.
 158    CRdsc 94   35    18.  3.
 160    CRdsc 94   42    21.  3.
 162    CRdsc 94   49    24.  3.
 164    CRdsc 94   56    27.  3.
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 166   CRdsc 94   63   30.  3.
 168   CRdsc 94   70   33.  3.
 170   CRdsc 94   77   36.  3.
 172   CRdsc 94   84   39.  3.
 174   CRdsr 94   102  41.  0.
 176   FAsup -5   102  41.  0.  0.      1.0
#176   CRfan -5   102  41.  0.
 #      second floor apartments (202  201 212  213 sum/west sum/east)
 200   CRw1  -22  1    4.   1.
 201   CRb1  -22  1    4.   1.
 202   CRd1  7    1    1.   1.
 203   CRho  5    1    1.5  1.5
 204   CRve  8    1    0.   3.
 205   CRda  88   1    6.   3.
 206   CRda  88   1    4.5  1.5
 210   CRw2  -21  2    4.   1.
 212   CRw1  -28  2    4.   1.
 213   CRw1  -28  2    4.   1.
 214   CRb1  -28  2    4.   1.
 215   CRd1  7    2    1.   1.
 216   CRho  6    2    1.5  1.5
 217   CRve  9    2    0.   3.
 218   CRda  89   2    6.   3.
 219   CRda  89   2    4.5  1.5
 240   CRw1  -24  3    4.   1.
 241   CRb1  -24  3    4.   1.
 242   CRd1  7    3    1.   1.
 243   CRho  5    3    1.5  1.5
 244   CRve  10   3    0.   3.
 245   CRda  90   3    6.   3.
 246   CRda  90   3    4.5  1.5
 250   CRw2  -25  4    4.   1.
 252   CRw1  -26  4    4.   1.
 253   CRw1  -26  4    4.   1.
 254   CRb1  -26  4    4.   1.
 255   CRd1  7    4    1.   1.
 256   CRho  6    4    1.5  1.5
 257   CRve  11   4    0.   3.
 258   CRda  91   4    6.   3.
 259   CRda  91   4    4.5  1.5
 270   CRwsw -23  5    4.   1.
 271   CRbsw -23  5    4.   1.
 272   CRdsw 7    5    1.   1.
 273   CRsvw 12   5    0.   3.
 274   CRdsaw 92  5    6.   3.
 280   CRwse -27  6    4.   1.
 281   CRbse -27  6    4.   1.
 282   CRdse 7    6    1.   1.
 283   CRsve 13   6    0.   3.
 284   CRdsae 93  6    6.   3.
 300   CRw1  -32  8    7.   1.
 301   CRb1  -32  8    7.   1.
 302   CRd1  14   8    1.   1.
 303   CRho  12   8    1.5  1.5
 304   CRve  15   8    0.   3.
 305   CRda  88   8    9.   3.
 306   CRda  88   8    7.5  1.5
 310   CRw2  -31  9    7.   1.
 312   CRw1  -38  9    7.   1.
 313   CRw1  -38  9    7.   1.
 314   CRb1  -38  9    7.   1.
 315   CRd1  14   9    1.   1.
 316   CRho  13   9    1.5  1.5
 317   CRve  16   9    0.   3.
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 318   CRda   89    9     9.    3.
 319   CRda   89    9     7.5   1.5
 340   CRw1   -34   10    7.    1.
 341   CRb1   -34   10    7.    1.
 342   CRd1   14    10    1.    1.
 343   CRho   12    10    1.5   1.5
 344   CRve   17    10    0.    3.
 345   CRda   90    10    9.    3.
 346   CRda   90    10    7.5   1.5
 350   CRw2   -35   11    7.    1.
 352   CRw1   -36   11    7.    1.
 353   CRw1   -36   11    7.    1.
 354   CRb1   -36   11    7.    1.
 355   CRd1   14    11    1.    1.
 356   CRho   13    11    1.5   1.5
 357   CRve   18    11    0.    3.
 358   CRda   91    11    9.    3.
 359   CRda   91    11    7.5   1.5
 370   CRwsw -33    12    7.    1.
 371   CRbsw -33    12    7.    1.
 372   CRdsw 14     12    1.    1.
 373   CRsvw 19     12    0.    3.
 374   CRdsaw 92    12    9.    3.
 380   CRwse -37    13    7.    1.
 381   CRbse -37    13    7.    1.
 382   CRdse 14     13    1.    1.
 383   CRsve 20     13    0.    3.
 384   CRdsae 93    13    9.    3.
 400   CRw1   -42   15    10.   1.
 401   CRb1   -42   15    10.   1.
 402   CRd1   21    15    1.    1.
 403   CRho   19    15    1.5   1.5
 404   CRve   22    15    0.    3.
 405   CRda   88    15    12.    3.
 406   CRda   88    15    10.5   1.5
 410   CRw2   -41   16    10.   1.
 412   CRw1   -48   16    10.   1.
 413   CRw1   -48   16    10.   1.
 414   CRb1   -48   16    10.   1.
 415   CRd1   21    16    1.    1.
 416   CRho   20    16    1.5   1.5
 417   CRve   23    16    0.    3.
 418   CRda   89    16    12.   3.
 419   CRda   89    16    10.5   1.5
 440   CRw1   -44   17    10.   1.
 441   CRb1   -44   17    10.   1.
 442   CRd1   21    17    1.    1.
 443   CRho   19    17    1.5   1.5
 444   CRve   24    17    0.    3.
 445   CRda   90    17    12.   3.
 446   CRda   90    17    10.5 1.5
 450   CRw2   -45   18    10.   1.
 452   CRw1   -46   18    10.   1.
 453   CRw1   -46   18    10.   1.
 454   CRb1   -46   18    10.   1.
 455   CRd1   21    18    1.    1.
 456   CRho   20    18    1.5   1.5
 457   CRve   25    18    0.    3.
 458   CRda   91    18    12.   3.
 459   CRda   91    18    10.5 1.5
 470   CRwsw -43    19    10.   1.
 471   CRbsw -43    19    10.   1.
 472   CRdsw 21     19    1.    1.
 473   CRsvw 26     19    0.    3.
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474   CRdsaw 92  19   12.  3.
480   CRwse -47  20   10.  1.
481   CRbse -47  20   10.  1.
482   CRdse 21   20   1.   1.
483   CRsve 27   20   0.   3.
484   CRdsae 93  20   12.  3.
500   CRw1  -52  22   13.  1.
501   CRb1  -52  22   13.  1.
502   CRd1  28   22   1.   1.
503   CRho  26   22   1.5  1.5
504   CRve  29   22   0.   3.
505   CRda  88   22   15.  3.
506   CRda  88   22   13.5 1.5
510   CRw2  -51  23   13.  1.
512   CRw1  -58  23   13.  1.
513   CRw1  -58  23   13.  1.
514   CRb1  -58  23   13.  1.
515   CRd1  28   23   1.   1.
516   CRho  27   23   1.5  1.5
517   CRve  30   23   0.   3.
518   CRda  89   23   15.  3.
519   CRda  89   23   13.5 1.5
540   CRw1  -54  24   13.  1.
541   CRb1  -54  24   13.  1.
542   CRd1  28   24   1.   1.
543   CRho  26   24   1.5  1.5
544   CRve  31   24   0.   3.
545   CRda  90   24   15.  3.
546   CRda  90   24   13.5 1.5
550   CRw2  -55  25   13.  1.
552   CRw1  -56  25   13.  1.
553   CRw1  -56  25   13.  1.
554   CRb1  -56  25   13.  1.
555   CRd1  28   25   1.   1.
556   CRho  27   25   1.5  1.5
557   CRve  32   25   0.   3.
558   CRda  91   25   15.  3.
559   CRda  91   25   13.5 1.5
570   CRwsw -53  26   13.  1.
571   CRbsw -53  26   13.  1.
572   CRdsw 28   26   1.   1.
573   CRsvw 33   26   0.   3.
574   CRdsaw 92  26   15.  3.
580   CRwse -57  27   13.  1.
581   CRbse -57  27   13.  1.
582   CRdse 28   27   1.   1.
583   CRsve 34   27   0.   3.
584   CRdsae 93  27   15.  3.
600   CRw1  -62  29   16.  1.
601   CRb1  -62  29   16.  1.
602   CRd1  35   29   1.   1.
603   CRho  33   29   1.5  1.5
604   CRve  36   29   0.   3.
605   CRda  88   29   18.  3.
606   CRda  88   29   16.5 1.5
613   CRw1  -68  30   16.  1.
614   CRb1  -68  30   16.  1.
615   CRd1  35   30   1.   1.
616   CRho  34   30   1.5  1.5
617   CRve  37   30   0.   3.
618   CRda  89   30   18.  3.
619   CRda  89   30   16.5 1.5
640   CRw1  -64  31   16.  1.
641   CRb1  -64  31   16.  1.
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642     CRdl   35    31    1.    1.
643     CRho   33    31    1.5   1.5
644     CRve   38    31    0.    3.
645     CRda   90    31    18.   3.
646     CRda   90    31    16.5 1.5
653     CRwl   -66   32    16.   1.
654     CRbl   -66   32    16.   1.
655     CRdl   35    32    1.    1.
656     CRho   34    32    1.5   1.5
657     CRve   39    32    0.    3.
658     CRda   91    32    18.   3.
659     CRda   91    32    16.5 1.5
670     CRwsw -63    33    16.   1.
671     CRbsw -63    33    16.   1.
672     CRdsw 35     33    1.    1.
673     CRsvw 40     33    0.    3.
674     CRdsaw 92    33    18.   3.
680     CRwse -67    34    16.   1.
681     CRbse -67    34    16.   1.
682     CRdse 35     34    1.    1.
683     CRsve 41     34    0.    3.
684     CRdsae 93    34    18.   3.
700     CRwl   -72   36    19.   1.
701     CRbl   -72   36    19.   1.
702     CRdl   42    36    1.    1.
703     CRho   40    36    1.5   1.5
704     CRve   43    36    0.    3.
705     CRda   88    36    21.   3.
706     CRda   88    36    19.5 1.5
713     CRwl   -78   37    19.   1.
714     CRbl   -78   37    19.   1.
715     CRdl   42    37    1.    1.
716     CRho   41    37    1.5   1.5
717     CRve   44    37    0.    3.
718     CRda   89    37    21.   3.
719     CRda   89    37    19.5 1.5
740     CRwl   -74   38    19.   1.
741     CRbl   -74   38    19.   1.
742     CRdl   42    38    1.    1.
743     CRho   40    38    1.5   1.5
744     CRve   45    38    0.    3.
745     CRda   90    38    21.   3.
746     CRda   90    38    19.5 1.5
753     CRwl   -76   39    19.   1.
754     CRbl   -76   39    19.   1.
755     CRdl   42    39    1.    1.
756     CRho   41    39    1.5   1.5
757     CRve   46    39    0.    3.
758     CRda   91    39    21.   3.
759     CRda   91    39    19.5 1.5
770     CRwsw -73    40    19.   1.
771     CRbsw -73    40    19.   1.
772     CRdsw 42     40    1.    1.
773     CRsvw 47     40    0.    3.
774     CRdsaw 92    40    21.   3.
780     CRwse -77    41    19.   1.
781     CRbse -77    41    19.   1.
782     CRdse 42     41    1.    1.
783     CRsve 48     41    0.    3.
784     CRdsae 93    41    21.   3.
800     CRwl   -82   43    22.   1.
801     CRbl   -82   43    22.   1.
802     CRdl   49    43    1.    1.
803     CRho   47    43    1.5   1.5
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804    CRve  50    43    0.    3.
805    CRda  88    43    24.   3.
806    CRda  88    43    22.5  1.5
813    CRw1  -88   44    22.   1.
814    CRb1  -88   44    22.   1.
815    CRd1  49    44    1.    1.
816    CRho  48    44    1.5   1.5
817    CRve  51    44    0.    3.
818    CRda  89    44    24.   3.
819    CRda  89    44    22.5  1.5
840    CRw1  -84   45    22.   1.
841    CRb1  -84   45    22.   1.
842    CRd1  49    45    1.    1.
843    CRho  47    45    1.5   1.5
844    CRve  52    45    0.    3.
845    CRda  90    45    24.   3.
846    CRda  90    45    22.5  1.5
853    CRw1  -86   46    22.   1.
854    CRb1  -86   46    22.   1.
855    CRd1  49    46    1.    1.
856    CRho  48    46    1.5   1.5
857    CRve  53    46    0.    3.
858    CRda  91    46    24.   3.
859    CRda  91    46    22.5  1.5
870    CRwsw -83   47    22.   1.
871    CRbsw -83   47    22.   1.
872    CRdsw 49    47    1.    1.
873    CRsvw 54    47    0.    3.
874    CRdsaw 92   47    24.   3.
880    CRwse -87   48    22.   1.
881    CRbse -87   48    22.   1.
882    CRdse 49    48    1.    1.
883    CRsve 55    48    0.    3.
884    CRdsae 93   48    24.   3.
900    CRw1  -92   50    25.   1.
901    CRb1  -92   50    25.   1.
902    CRd1  56    50    1.    1.
903    CRho  54    50    1.5   1.5
904    CRve  57    50    0.    3.
905    CRda  88    50    27.   3.
906    CRda  88    50    25.5  1.5
913    CRw1  -98   51    25.   1.
914    CRb1  -98   51    25.   1.
915    CRd1  56    51    1.    1.
916    CRho  55    51    1.5   1.5
917    CRve  58    51    0.    3.
918    CRda  89    51    27.   3.
919    CRda  89    51    25.5  1.5
940    CRw1  -94   52    25.   1.
941    CRb1  -94   52    25.   1.
942    CRd1  56    52    1.    1.
943    CRho  54    52    1.5   1.5
944    CRve  59    52    0.    3.
945    CRda  90    52    27.   3.
946    CRda  90    52    25.5  1.5
953    CRw1  -96   53    25.   1.
954    CRb1  -96   53    25.   1.
955    CRd1  56    53    1.    1.
956    CRho  55    53    1.5   1.5
957    CRve  60    53    0.    3.
958    CRda  91    53    27.   3.
959    CRda  91    53    25.5  1.5
970    CRwsw -93   54    25.   1.
971    CRbsw -93   54    25.   1.
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 972   CRdsw 56    54   1.   1.
 973   CRsvw 61    54   0.   3.
 974   CRdsaw 92   54   27.  3.
 980   CRwse -97   55   25.  1.
 981   CRbse -97   55   25.  1.
 982   CRdse 56    55   1.   1.
 983   CRsve 62    55   0.   3.
 984   CRdsae 93   55   27.  3.
 1000  CRw1   -102 57   28.  1.
 1001  CRb1   -102 57   28.  1.
 1002  CRd1   63   57   1.   1.
 1003  CRho   61   57   1.5  1.5
 1004  CRve   64   57   0.   3.
 1005  CRda   88   57   30.  3.
 1006  CRda   88   57   28.5 1.5
 1013  CRw1   -108 58   28.  1.
 1014  CRb1   -108 58   28.  1.
 1015  CRd1   63   58   1.   1.
 1016  CRho   62   58   1.5  1.5
 1017  CRve   65   58   0.   3.
 1018  CRda   89   58   30.  3.
 1019  CRda   89   58   28.5 1.5
 1040  CRw1   -104 59   28.  1.
 1041  CRb1   -104 59   28.  1.
 1042  CRd1   63   59   1.   1.
 1043  CRho   61   59   1.5  1.5
 1044  CRve   66   59   0.   3.
 1045  CRda   90   59   30.  3.
 1046  CRda   90   59   28.5 1.5
 1053  CRw1   -106 60   28.  1.
 1054  CRb1   -106 60   28.  1.
 1055  CRd1   63   60   1.   1.
 1056  CRho   62   60   1.5  1.5
 1057  CRve   67   60   0.   3.
 1058  CRda   91   60   30.  3.
 1059  CRda   91   60   28.5 1.5
 1070  CRwsw -103  61   28.  1.
 1071  CRbsw -103  61   28.  1.
 1072  CRdsw 63    61   1.   1.
 1073  CRsvw 68    61   0.   3.
 1074  CRdsaw 92   61   30.  3.
 1080  CRwse -107  62   28.  1.
 1081  CRbse -107  62   28.  1.
 1082  CRdse 63    62   1.   1.
 1083  CRsve 69    62   0.   3.
 1084  CRdsae 93   62   30.  3.
 1100  CRw1   -112 64   31.  1.
 1101  CRb1   -112 64   31.  1.
 1102  CRd1   70   64   1.   1.
 1103  CRho   68   64   1.5  1.5
 1104  CRve   71   64   0.   3.
 1105  CRda   88   64   33.  3.
 1106  CRda   88   64   31.5 1.5
 1113  CRw1   -118 65   31.  1.
 1114  CRb1   -118 65   31.  1.
 1115  CRd1   70   65   1.   1.
 1116  CRho   69   65   1.5  1.5
 1117  CRve   72   65   0.   3.
 1118  CRda   89   65   33.  3.
 1119  CRda   89   65   31.5 1.5
 1140  CRw1   -114 66   31.  1.
 1141  CRb1   -114 66   31.  1.
 1142  CRd1   70   66   1.   1.
 1143  CRho   68   66   1.5  1.5
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1144  CRve   73    66   0.   3.
1145  CRda   90    66   33.  3.
1146  CRda   90    66   31.5 1.5
1153  CRw1   -116  67   31.  1.
1154  CRb1   -116  67   31.  1.
1155  CRd1   70    67   1.   1.
1156  CRho   69    67   1.5  1.5
1157  CRve   74    67   0.   3.
1158  CRda   91    67   33.  3.
1159  CRda   91    67   31.5 1.5
1170  CRwsw  -113  68   31.  1.
1171  CRbsw  -113  68   31.  1.
1172  CRdsw  70    68   1.   1.
1173  CRsvw  75    68   0.   3.
1174  CRdsaw 92    68   33.  3.
1180  CRwse  -117  69   31.  1.
1181  CRbse  -117  69   31.  1.
1182  CRdse  70    69   1.   1.
1183  CRsve  76    69   0.   3.
1184  CRdsae 93    69   33.  3.
1200  CRw1   -122  71   34.  1.
1201  CRb1   -122  71   34.  1.
1202  CRd1   77    71   1.   1.
1203  CRho   75    71   1.5  1.5
1204  CRve   78    71   0.   3.
1205  CRda   88    71   36.  3.
1206  CRda   88    71   34.5 1.5
1213  CRw1   -128  72   34.  1.
1214  CRb1   -128  72   34.  1.
1215  CRd1   77    72   1.   1.
1216  CRho   76    72   1.5  1.5
1217  CRve   79    72   0.   3.
1218  CRda   89    72   36.  3.
1219  CRda   89    72   34.5 1.5
1240  CRw1   -124  73   34.  1.
1241  CRb1   -124  73   34.  1.
1242  CRd1   77    73   1.   1.
1243  CRho   75    73   1.5  1.5
1244  CRve   80    73   0.   3.
1245  CRda   90    73   36.  3.
1246  CRda   90    73   34.5 1.5
1253  CRw1   -126  74   34.  1.
1254  CRb1   -126  74   34.  1.
1255  CRd1   77    74   1.   1.
1256  CRho   76    74   1.5  1.5
1257  CRve   81    74   0.   3.
1258  CRda   91    74   36.  3.
1259  CRda   91    74   34.5 1.5
1270  CRwsw  -123  75   34.  1.
1271  CRbsw  -123  75   34.  1.
1272  CRdsw  77    75   1.   1.
1273  CRsvw  82    75   0.   3.
1274  CRdsaw 92    75   36.  3.
1280  CRwse  -127  76   34.  1.
1281  CRbse  -127  76   34.  1.
1282  CRdse  77    76   1.   1.
1283  CRsve  83    76   0.   3.
1284  CRdsae 93    76   36.  3.
1300  CRw1   -132  78   37.  1.
1301  CRb1   -132  78   37.  1.
1302  CRd1   84    78   1.   1.
1303  CRho   82    78   1.5  1.5
1305  CRda   88    78   39.  3.
1306  CRda   88    78   37.5 1.5
```

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 1313  CRw1   -138 79   37.  1.
 1314  CRb1   -138 79   37.  1.
 1315  CRd1   84   79   1.   1.
 1316  CRho   83   79   1.5  1.5
 1318  CRda   89   79   39.  3.
 1319  CRda   89   79   37.5 1.5
 1340  CRw1   -134 80   37.  1.
 1341  CRb1   -134 80   37.  1.
 1342  CRd1   84   80   1.   1.
 1343  CRho   82   80   1.5  1.5
 1345  CRda   90   80   39.  3.
 1346  CRda   90   80   37.5 1.5
 1353  CRw1   -136 81   37.  1.
 1354  CRb1   -136 81   37.  1.
 1355  CRd1   84   81   1.   1.
 1356  CRho   83   81   1.5  1.5
 1358  CRda   91   81   39.  3.
 1359  CRda   91   81   37.5 1.5
 1370  CRwsw -133 82   37.  1.
 1371  CRbsw -133 82   37.  1.
 1372  CRdsw 84   82   1.   1.
 1374  CRdsaw 92  82   39.  3.
 1380  CRwse -137 83   37.  1.
 1381  CRbse -137 83   37.  1.
 1382  CRdse 84   83   1.   1.
 1384  CRdsae 93  83   39.  3.
 1400  CRdr1 88   96   41.  0.
 1401  FAr1  96   -1   0.   41. 0.      1.10
#1401  CRfan 96   -1   0.   41.
 1402  CRdr1 89   97   41.  0.
 1403  FAr1  97   -1   0.   41. 0.      1.10
#1403  CRfan 97   -1   0.   41.
 1404  CRdr1 90   98   41.  0.
 1495  FAr1  98   -1   0.   41. 0.      1.10
#1495  CRfan 98   -1   0.   41.
 1406  CRdr1 91   99   41.  0.
 1407  FAr1  99   -1   0.   41. 0.      1.10
#1407  CRfan 99   -1   0.   41.
 1408  CRdrw 92   100  41.  0.
 1409  FArw  100  -1   0.   41. 0.      1.10
#1409  CRfan 100  -1   0.   41.
 1410  CRdre 93   101  41.  0.
 1411  FAre  101  -1   0.   41. 0.      1.10
#1411  CRfan 101  -1   0.   41.


&-CP-BUILding reference height for Cp data 32 - OPTIONAL DATASECTION ---
  ___________
 | Height    |
 | (m)       |
 |___________|
 40

&-CP-VALUes                     33         --- OPTIONAL DATASECTION ---
  _______________
 |1.|Dataset Name |
 |__|_____________|
     non
```

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 ____________________________________________________________________________________________
|2.|Facade|     Winddirection               ( first line )                                   |
|__|Elemno|     Cp Values                   ( second and following lines )                   |
|* (-)    |(deg)    |[deg]    |[deg]    |[deg]    |[deg]    |[deg]    |[deg]    |[deg]    |[deg]    |
|_________|_________|_________|_________|_________|_________|_________|_________|_________|_________|
*          0.        45.       90.       135.      180.      225.      270.      315.
1          -0.5      -0.5      -0.5      -0.5      -0.5      -0.5      -0.5      -0.5
2          0.        0.        0.        0.        0.        0.        0.        0.
3          0.        0.        0.        0.        0.        0.        0.        0.
4          0.        0.        0.        0.        0.        0.        0.        0.
5          0.6       0.4       0.6       -0.3      -0.5      -0.3      -0.5      -0.3
6          0.        0.        0.        0.        0.        0.        0.        0.
7          0.        0.        0.        0.        0.        0.        0.        0.
8          0.        0.        0.        0.        0.        0.        0.        0.
9          0.        0.        0.        0.        0.        0.        0.        0.
10         0.        0.        0.        0.        0.        0.        0.        0.
11         -0.5      -0.3      -0.5      -0.3      0.6       0.4       0.6       -0.3
12         0.6       -0.3      -0.5      -0.3      -0.5      -0.3      0.6       0.4
13         0.6       -0.3      -0.5      -0.3      -0.5      -0.3      0.6       0.4
14         0.6       -0.3      -0.5      -0.3      -0.5      -0.3      0.6       0.4
15         0.6       0.4       0.6       -0.3      -0.5      -0.3      -0.5      -0.3
16         -0.5      -0.3      0.6       0.4       0.6       -0.3      -0.5      -0.3
17         -0.5      -0.3      0.6       0.4       0.6       -0.3      -0.5      -0.3
18         -0.5      -0.3      0.6       0.4       0.6       -0.3      -0.5      -0.3
19         0.        0.        0.        0.        0.        0.        0.        0.
20         0.        0.        0.        0.        0.        0.        0.        0.
21         -0.5      -0.3      -0.5      -0.3      0.6       0.4       0.6       -0.3
22         0.        -0.3      -0.5      -0.3      -0.5      -0.3      0.6       0.4
23         0.3       -0.3      -0.5      -0.3      -0.5      -0.3      0.3       0.4
24         0.6       -0.3      -0.5      -0.3      -0.5      -0.3      0.        0.4
25         0.6       0.4       0.6       -0.3      -0.5      -0.3      -0.5      -0.3
26         -0.5      -0.3      0.6       0.4       0.        -0.3      -0.5      -0.3
27         -0.5      -0.3      0.3       0.4       0.3       -0.3      -0.5      -0.3
28         -0.5      -0.3      0.        0.4       0.6       -0.3      -0.5      -0.3
29         0.        0.        0.        0.        0.        0.        0.        0.
30         0.        0.        0.        0.        0.        0.        0.        0.
31         -0.5      -0.3      -0.5      -0.3      0.6       0.38      0.6       -0.3
32         0.        -0.3      -0.5      -0.3      -0.5      -0.3      0.6       0.38
33         0.3       -0.3      -0.5      -0.3      -0.5      -0.3      0.3       0.38
34         0.6       -0.3      -0.5      -0.3      -0.5      -0.3      0.        0.38
35         0.6       0.38      0.6       -0.3      -0.5      -0.3      -0.5      -0.3
36         -0.5      -0.3      0.6       0.38      0.        -0.3      -0.5      -0.3
37         -0.5      -0.3      0.3       0.38      0.3       -0.3      -0.5      -0.3
38         -0.5      -0.3      0.        0.38      0.6       -0.3      -0.5      -0.3
39         0.        0.        0.        0.        0.        0.        0.        0.
40         0.        0.        0.        0.        0.        0.        0.        0.
41         -0.5      -0.3      -0.5      -0.3      0.6       0.4       0.6       -0.3
42         0.        -0.3      -0.5      -0.3      -0.5      -0.3      0.6       0.4
43         0.3       -0.3      -0.5      -0.3      -0.5      -0.3      0.3       0.4
44         0.6       -0.3      -0.5      -0.3      -0.5      -0.3      0.        0.4
45         0.6       0.4       0.6       -0.3      -0.5      -0.3      -0.5      -0.3
46         -0.5      -0.3      0.6       0.4       0.        -0.3      -0.5      -0.3
47         -0.5      -0.3      0.3       0.4       0.3       -0.3      -0.5      -0.3
48         -0.5      -0.3      0.        0.4       0.6       -0.3      -0.5      -0.3
49         0.        0.        0.        0.        0.        0.        0.        0.
50         0.        0.        0.        0.        0.        0.        0.        0.
51         -0.5      -0.3      -0.5      -0.3      0.6       0.47      0.6       -0.3
52         0.        -0.3      -0.5      -0.3      -0.5      -0.3      0.6       0.47
53         0.3       -0.3      -0.5      -0.3      -0.5      -0.3      0.3       0.47
54         0.6       -0.3      -0.5      -0.3      -0.5      -0.3      0.        0.47
55         0.6       0.47      0.6       -0.3      -0.5      -0.3      -0.5      -0.3
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56         -0.5   -0.3   0.6    0.47   0.     -0.3   -0.5   -0.3
57         -0.5   -0.3   0.3    0.47   0.3    -0.3   -0.5   -0.3
58         -0.5   -0.3   0.     0.47   0.6    -0.3   -0.5   -0.3
59         0.     0.     0.     0.     0.     0.     0.     0.
60         0.     0.     0.     0.     0.     0.     0.     0.
61         -0.5   -0.3   -0.5   -0.3   0.6    0.54   0.6    -0.3
62         0.     -0.3   -0.5   -0.3   -0.5   -0.3   0.6    0.54
63         0.3    -0.3   -0.5   -0.3   -0.5   -0.3   0.3    0.54
64         0.6    -0.3   -0.5   -0.3   -0.5   -0.3   0.     0.54
65         0.6    0.54   0.6    -0.3   -0.5   -0.3   -0.5   -0.3
66         -0.5   -0.3   0.6    0.54   0.     -0.3   -0.5   -0.3
67         -0.5   -0.3   0.3    0.54   0.3    -0.3   -0.5   -0.3
68         -0.5   -0.3   0.     0.54   0.6    -0.3   -0.5   -0.3
69         0.     0.     0.     0.     0.     0.     0.     0.
70         0.     0.     0.     0.     0.     0.     0.     0.
71         -0.5   -0.3   -0.5   -0.3   0.7    0.6    0.7    -0.3
72         0.     -0.3   -0.5   -0.3   -0.5   -0.3   0.7    0.6
73         0.35   -0.3   -0.5   -0.3   -0.5   -0.3   0.35   0.6
74         0.7    -0.3   -0.5   -0.3   -0.5   -0.3   0.     0.6
75         0.7    0.6    0.7    -0.3   -0.5   -0.3   -0.5   -0.3
76         -0.5   -0.3   0.7    0.6    0.     -0.3   -0.5   -0.3
77         -0.5   -0.3   0.35   0.6    0.35   -0.3   -0.5   -0.3
78         -0.5   -0.3   0.     0.6    0.7    -0.3   -0.5   -0.3
79         0.     0.     0.     0.     0.     0.     0.     0.
80         0.     0.     0.     0.     0.     0.     0.     0.
81         -0.5   -0.3   -0.5   -0.3   0.7    0.67   0.7    -0.3
82         0.     -0.3   -0.5   -0.3   -0.5   -0.3   0.7    0.67
83         0.35   -0.3   -0.5   -0.3   -0.5   -0.3   0.35   0.67
84         0.7    -0.3   -0.5   -0.3   -0.5   -0.3   0.     0.67
85         0.7    0.67   0.7    -0.3   -0.5   -0.3   -0.5   -0.3
86         -0.5   -0.3   0.7    0.67   0.     -0.3   -0.5   -0.3
87         -0.5   -0.3   0.35   0.67   0.35   -0.3   -0.5   -0.3
88         -0.5   -0.3   0.     0.67   0.7    -0.3   -0.5   -0.3
89         0.     0.     0.     0.     0.     0.     0.     0.
90         0.     0.     0.     0.     0.     0.     0.     0.
91         -0.5   -0.3   -0.5   -0.3   0.8    0.72   0.8    -0.3
92         0.     -0.3   -0.5   -0.3   -0.5   -0.3   0.8    0.72
93         0.4    -0.3   -0.5   -0.3   -0.5   -0.3   0.4    0.72
94         0.8    -0.3   -0.5   -0.3   -0.5   -0.3   0.     0.72
95         0.8    0.72   0.8    -0.3   -0.5   -0.3   -0.5   -0.3
96         -0.5   -0.3   0.8    0.72   0.     -0.3   -0.5   -0.3
97         -0.5   -0.3   0.4    0.72   0.4    -0.3   -0.5   -0.3
98         -0.5   -0.3   0.     0.72   0.8    -0.3   -0.5   -0.3
99         0.     0.     0.     0.     0.     0.     0.     0.
100        0.     0.     0.     0.     0.     0.     0.     0.
101        -0.5   -0.3   -0.5   -0.3   0.8    0.78    0.8    -0.3
102        0.     -0.3   -0.5   -0.3   -0.5   -0.3   0.8    0.78
103        0.4    -0.3   -0.5   -0.3   -0.5   -0.3   0.4    0.78
104        0.8    -0.3   -0.5   -0.3   -0.5   -0.3   0.     0.78
105        0.8    0.78    0.8    -0.3   -0.5   -0.3   -0.5   -0.3
106        -0.5   -0.3   0.8    0.78    0.     -0.3   -0.5   -0.3
107        -0.5   -0.3   0.4    0.78    0.4    -0.3   -0.5   -0.3
108        -0.5   -0.3   0.     0.78    0.8    -0.3   -0.5   -0.3
109        0.     0.     0.     0.     0.     0.     0.     0.
110        0.     0.     0.     0.     0.     0.     0.     0.
111        -0.5   -0.3   -0.5   -0.3   0.9    0.8    0.9    -0.3
112        0.     -0.3   -0.5   -0.3   -0.5   -0.3   0.9    0.8
113        0.45   -0.3   -0.5   -0.3   -0.5   -0.3   0.45   0.8
114        0.9    -0.3   -0.5   -0.3   -0.5   -0.3   0.     0.8
115        0.9    0.8    0.9    -0.3   -0.5   -0.3   -0.5   -0.3
116        -0.5   -0.3   0.9    0.8    0.     -0.3   -0.5   -0.3
117        -0.5   -0.3   0.45   0.8    0.45   -0.3   -0.5   -0.3
118        -0.5   -0.3   0.     0.8    0.9    -0.3   -0.5   -0.3
119        0.     0.     0.     0.     0.     0.     0.     0.
```

```
 120        0.     0.     0.     0.     0.     0.     0.     0.
 121        -0.5   -0.3   -0.5   -0.3   0.8    0.72   0.8    -0.3
 122        0.     -0.3   -0.5   -0.3   -0.5   -0.3   0.8    0.72
 123        0.4    -0.3   -0.5   -0.3   -0.5   -0.3   0.4    0.72
 124        0.8    -0.3   -0.5   -0.3   -0.5   -0.3   0.     0.72
 125        0.8    0.72   0.8    -0.3   -0.5   -0.3   -0.5   -0.3
 126        -0.5   -0.3   0.8    0.72   0.     -0.3   -0.5   -0.3
 127        -0.5   -0.3   0.4    0.72   0.4    -0.3   -0.5   -0.3
 128        -0.5   -0.3   0.     0.72   0.8    -0.3   -0.5   -0.3
 129        0.     0.     0.     0.     0.     0.     0.     0.
 130        0.     0.     0.     0.     0.     0.     0.     0.
 131        -0.5   -0.3   -0.5   -0.3   0.75   0.65   0.75   -0.3
 132        0.     -0.3   -0.5   -0.3   -0.5   -0.3   0.75   0.65
 133        0.4    -0.3   -0.5   -0.3   -0.5   -0.3   0.4    0.65
 134        0.75   -0.3   -0.5   -0.3   -0.5   -0.3   0.     0.65
 135        0.75   0.65   0.75   -0.3   -0.5   -0.3   -0.5   -0.3
 136        -0.5   -0.3   0.75   0.65   0.     -0.3   -0.5   -0.3
 137        -0.5   -0.3   0.4    0.65   0.4    -0.3   -0.5   -0.3
 138        -0.5   -0.3   0.     0.65   0.75   -0.3   -0.5   -0.3

&-SCH-METeo data                    36        --- OPTIONAL DATASECTION ---
  _____________________
 |1.|Dataset Name      |
 |__|__________________|
   help
# F:boston.bin DOE2

  ___________________________________________________________________________________
 |2.|Time               |       Wind            |Temperature|Humidity|Barometer|
 |__|                   |_______________________|           |        |Pressure |
 |                      | Speed   |Direction    |           |        |Absolute |
 |(-)                   |(m/sec)  |(deg)        |(oC)       |[g/kg]  |[kPa]    |
 |______________________|_________|_____________|___________|________|_________|
 1992jan01_0:00          0.0       315.           20.         0.        103.5
 1992jan01_1:00          4.0       315.           20.         0.        103.5
 1992jan01_2:00          8.0       315.           20.         0.        103.5
#1992jan01_3:00          12.       315.           20.         0.        103.5
 1992jan01_4:00          0.0       315.           0.        0.        103.5
 1992jan01_5:00          4.0       315.           0.        0.        103.5
 1992jan01_6:00          8.0       315.           0.        0.        103.5
#1992jan01_7:00          12.       315.           0.        0.        103.5
 1992jan01_8:00          0.0       315.           -20.        0.        103.5
 1992jan01_9:00          4.0       315.           -20.        0.        103.5
 1992jan01_10:00          8.0       315.           -20.        0.        103.5
#1992jan01_11:00          12.       315.           -20.        0.        103.5
```