AIR INFILTRATION REDUCTION IN EXISTING BUILDINGS

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PAPER 13

RETROFIT-PLANNING-TOOLS FOR INSTITUTIONAL AND RESIDENTIAL BUILDINGS WITH USER INFLUENCED AIR INFILTRATION

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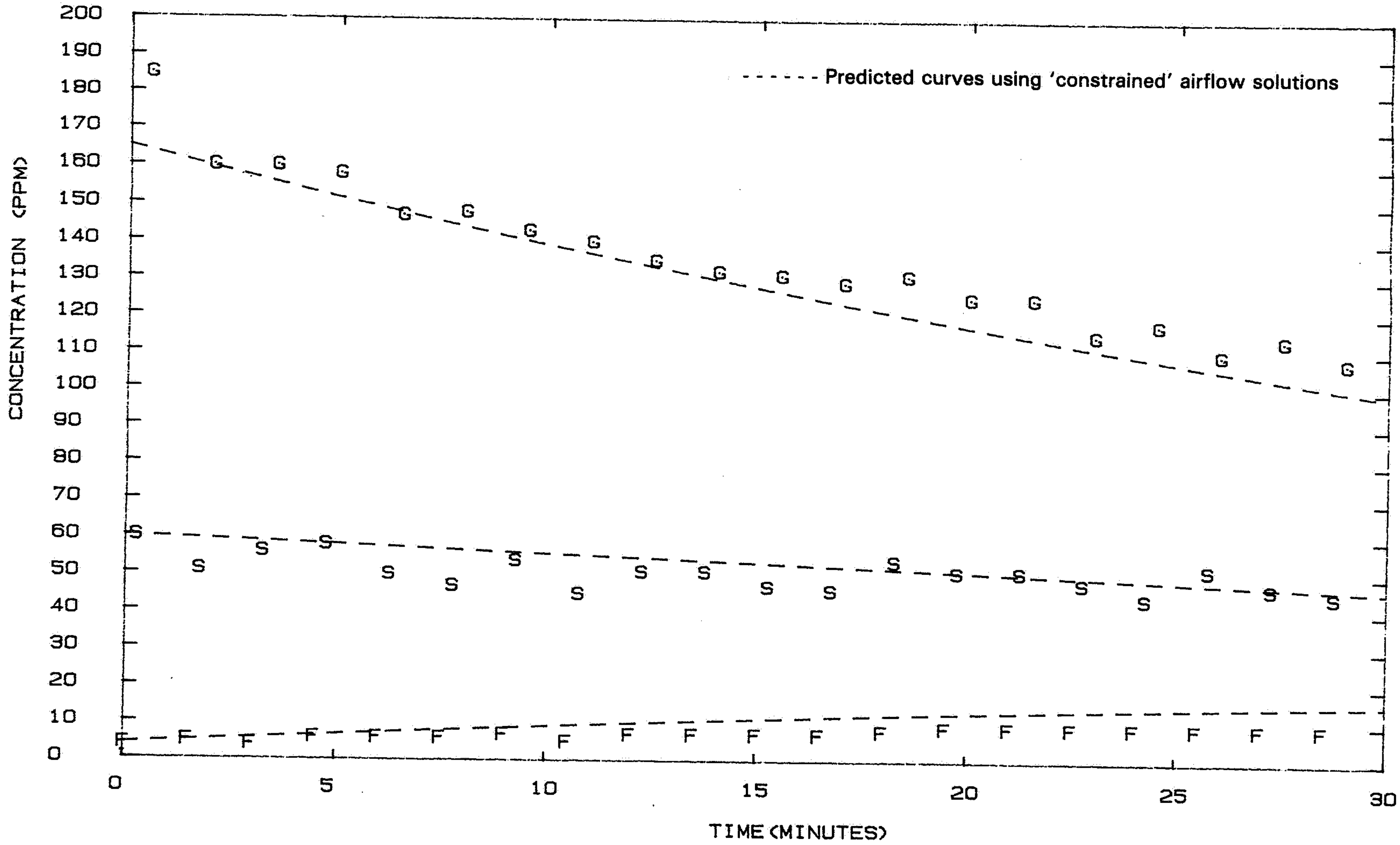
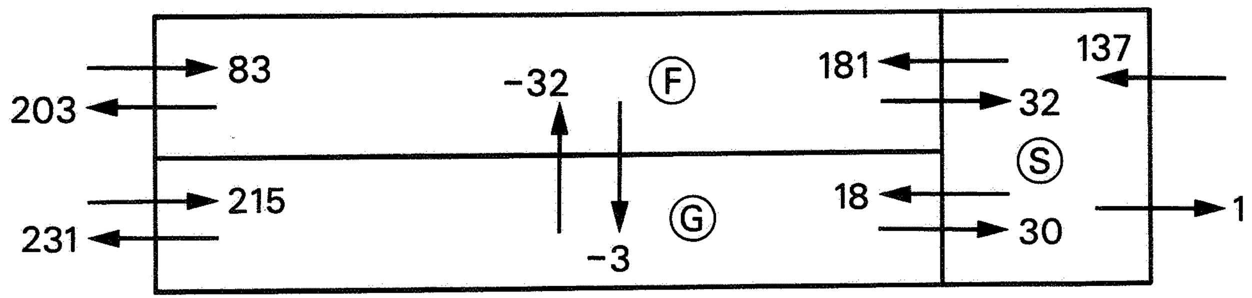
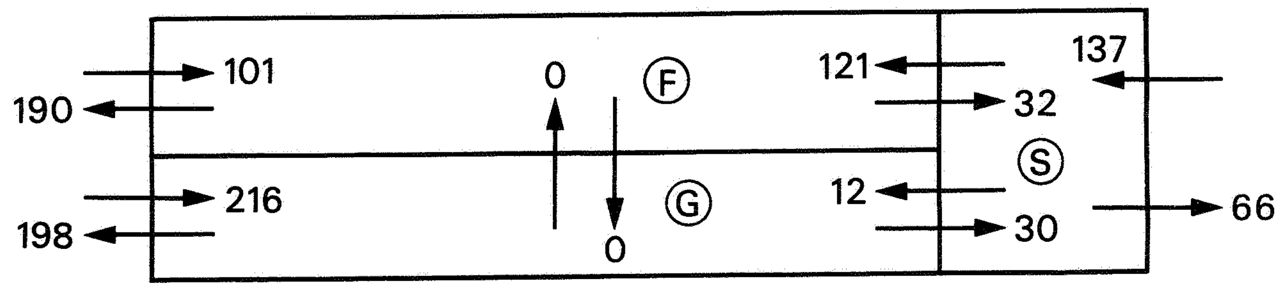


Figure 3 Building 10 – Nitrous oxide concentrations



'Unconstrained' solution



'Constrained' solution

Figure 4 Inter-zone airflows in litres/sec

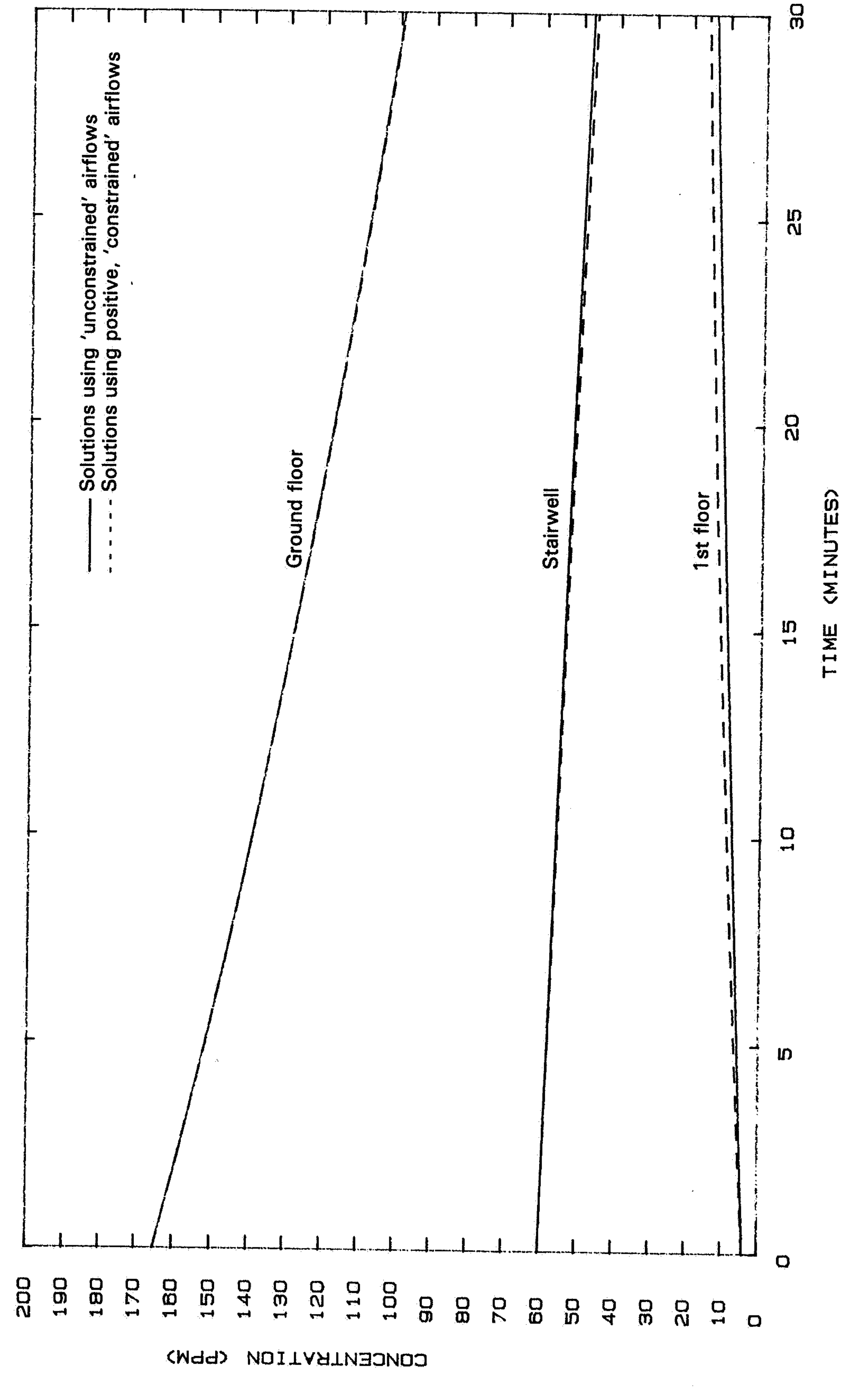


Figure 5 Predicted nitrous oxide concentrations

SYNOPSIS

The authors present a survey on the actual retrofit-planning methods in connection with the air change-situation in houses, how they are used by Swiss energy-consultants. Air exchange happens in Swiss and most other Central European houses by a superposition of infiltration, some single exhaust fans and window openings.
Inspite of refined analysis and planning methods, developed and published by research institutes, the actual planning situation by experts is poor, caused partly by cost effectivness-reasons and by a too small knowledge-transfer.
Main emphasis is given to a presentation of a new grafic method, which delivers values of mean air change rates, but also checks minimum and maximum values. Based on detailed calculation, this method demandes only few construction input data and preferably pressurisation values and window opening data.

1. INTRODUCTION, SCOPE

After discussions with a number of energy consultants, and also following on own experiences in this field we felt the existence of an uncertainity in connection with questions of air exchange in buildings. An example may explain this situation: an energy consultant may have some doubts about the thermal conductivity of some wall layers. But nervertheless he will be able to calculate the k-value of the wall within a precision of about ± 10 ÷ 20 %. Estimation on infiltration rates may - without additional measurement - well be within ± 50 ÷ 100 % of the true value.
There exists a worldwide activity on audit techniques for infiltration, on calculation methods about air exchange. But there is a poor knowledge transfer to the practicing consultants. As background for a better understanding a few highlights on typical Swiss (Central European) conditions in the institutional and residential sector are to be mentioned:
- large variety of constructions (especially in tightness)
- large stock of buildings to be retrofitted, small quantity of new units per year,
- climate and air pollution situation not demanding a mechanical ventilation in most cases,
- old habit of "window opening".

Many publications in foreign journals, as the AICHandbook [1], as Gertis [2] and others demonstrate the advantages of a controlled ventilation, preferably with heat recovery. Other authors as Blaich and Sell [3], Haltiner [4], Wegner [5] warn against the danger of an uncontrolled air exchange situation, which may cause humidity problems, odour - or poisoning problems. All these papers may well demonstrate the general situation or some special aspects. What the energy consultants really need is a cost effective auditing and planning method, taking into account these warnings, and which is applicable for the existing building stock. We think, that critical papers of Harryson [6] and of Krüger/Hausladen [7] show necessary steps to get these tools.

It is the scope of this paper, to display and critizise existing planning tools for the determination of the air exchange in houses, to explain new grafical tools, which are in a draft state and to show the necessity of reasonable building codes.

2. ACTUAL PLANNING TOOLS; USED BY SWISS CONSULTANTS

2.1 Problems of understanding

There are different reasons, e.g. an insufficient education in building physics, which cause difficulties in understanding infiltration phenomena. On the other hand these phenomena are more complex as others. Some of these problems are demonstrated:

- Air exchange in our houses occures not only due to a single action, as
  - natural infiltration (open and closed windows)
  - ventilation through shafts
  - mechanical ventilation,

  but due to their superposition. It is a pitty that many authors of papers do not point out the system, which they are describing.
- Similar complaints concern also publications and handbooks, which do not properly distinguish between
  - infiltration rates, valid for design conditions of the heating system,
  - mean infiltration with closed window conditions through a certain period,
  - mean infiltration in an occupied house through a certain period,
  - extreme infiltration, caused by special climate or user-conditions.

According the problem a specific date set is necessary.

A third mistake has to be mentioned:
Infiltration discussions or - calculations are too often based only on window and door gaps. We think, that after the TN 1 of AIC or after similar Swiss test results [8] it should be recognized, how important it is to judge on facade-leakage rates. Corresponding data are missing for most Swiss building types and also depending on aging or drying conditions. Some studies are made, which are listed below:

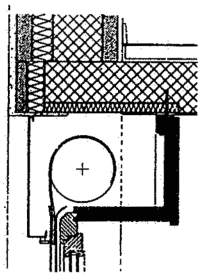
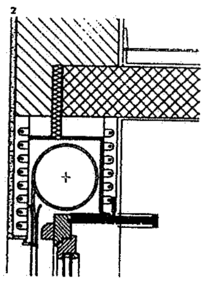
- Infiltration an leakage measurements of selected Swiss multifamily buildings including different construction types by Haerter and Steinemann, together with EMPA [9];
- A research project on the control of ventilation in Swiss timber construction buildings by Sell and Michel (EMPA, section Holz, Dübendorf)
- A report on the leakage of typical Swiss roller-blind-constructions and the corresponding handler (report EMPA Nr. 45160, 1982), (see fig. 1)
- A complementary work to the first project for additional types of buildings (through EMPA, H. Mühlebach/P. Hartmann and subcontractors).

Actual planning tools "air-change in residential buildings" (mean air changes)

Method	Advantage	Disadvantage	Possible errors	Practicability to judge retrofit errors
A "Estimation by observation" (of components)	quick, cheap, no tests	big errors, especially for consultants without any experience in testing of leakage		no
B Calculation of ventilation (losses) within energy balance	energy budget fits with this air changevalue	errors in a range of factor 2 well possible because of uncertainities in other parameters; errors smaller through combination with A		yes, in principle; problem of user reaction to changes
C Calculation of ventilation as sum of different effects (e.g. window doors ....)	well applicable to buildings with mainly mechanical ventilation	similar errors as method A, but higher effort to calculate	errors in range of factor 3 for tighter houses, factor 2 for leakly ones	yes, in principle, but dangerous to believe in these "calculated values"; user effects?
D Direct grafical determination of the air change, including a standard user influence	quick; experience of many research projects can be included in this tables	result should be cross-checked, to reach much higher accuracy as A÷C	factor 1.5 (÷2)	yes, generally

Fig.1 "Calculation values" for air leakage of roller blinds and handles

a) Leakage of the cage

Type of cage		sealing/tightness	leakage a [$m^3/h \cdot m \cdot Pa^{2/3}$]
inside of wall vertical service cover		good sealing no special sealing	0.015 0.10
integra-grated in wall/ ceiling; horizontal service-cover		good sealing no special sealing	0.03 0.15

b) Leakage of handle

Type	design / workmenship	Leakage [$m^3/h \cdot Pa^{2/3}$]
strap	- rather tight - rather leaky	0.08 0.02
handle	- tight plastic - enclosure for penetrating axle - metallic enclosure arround axle	0.045 0.19

2. TARGETS FOR RETROFITING OF BUILDINGS

In most cases retrofit actions at our buildings are combinating energy conservation measures with maintenance. Building codes or energy consultants set energy targets, building owners set financial targets or limits. Energy consultants, at least for residential buildings, rarely set air-change targets. Target values, as those of the Swedish Standard (cited in [10], pp 283) or in the new ASHRAE-Standard [11] slowly get introduced.
This unsifficient situation is not based on the lazyness of these consultants, but on the economical constraint. Building owners are not willing to pay more than about 500 - 1000 Swiss francs for a retrofit plan of a single family house or maybe a few thousand francs for a multifamily house. Therefore energy consultants are restricted to observations and empirical rules, which they cannot check. Only few experts are using any measurement equipment.

2.3 Measurement tools, actually used by consultants

(The following comments use the same structure as the corresponding table A 11.1 in [1])

There is no standard test procedure for checking existing buildings, which would be used nationwide. Only about half a dozen of Swiss experts posses more refined measurement tools.

Air change date would interest (condensation, energy, hygienic problems), especially long term tests. It may be, that cheaper systems with lower precision, which are under first tests, will promote these tests later. - Few consultants use pressurisation-equipments; but there is a big lack of target-values for this interesting reproducable procedure. - Some others use infrared cameras for a qualitative demonstration of ecessive infiltration. Inspite of these attempts most consultants use only the "observation method", paper-sheet-tests for windows or the smoke-pouncil-method for qualitative descriptions.
Exellent equipment and methods as presented e.g. by Lundin[12], Shaw [13] cannot be afforded.

2.4 Planning tools used by consultatns

A following table shows and judges existing planning tools. All 4 methods are quick and do not demand extensive measurements and observation. As consequence they may include errors in the range of a factor 2 to 3, as long as there is not a certain cross-check possibility.
It seems necessary to include some measurements for a more valide description of an actual exchange situation in a building and especially for any planning of retrofit - measures.

Fig. 2 Direct estimation method for mean air change rates, including "Standard users"

Mean air change* [h^{-1}] (during heating season including standard user influence)

	single family house roof top apartment corner house of row	building shell tightness (window,wall,roof)		multi family house center house of row-houses	
Wind-class	Exposure	rather tight	rather leaky	Exposure	Wind-class
I or II		0.5	0.65	rather protected	I or II
	rather protected	0.6	0.8		
		0.65	0.8	exposed	
	exposed	0.8	1.0		
III or IV		0.65	0.8	rather protected	III or IV
	rather protected	0.8	1.0		
		0.8	1.1	exposed	
	exposed	1.0	1.4		

* Necessary multiplication factors for above values:

- rooms with shafts or open chimneys
  1.1 ÷ 1.4
  (leaky rooms) (tight rooms)
- open high rooms with a rather leaky roof : 1.3

One example may explain this situation:
a rule of thumb says, that the factor
n_B / n_o = air-change, occupied / air change, closed windows is about 2 ÷ 4. For a large residential block in a windy situation we checked this rule and got a factor of about 1.2 · 1.3. This happend, because of a very resticitve heating set-point and the fact, that it seems dangerous to leave windows open during any absence because of wind and rain-damages.

3. OTHER, NEW TOOLS

3.1 New methods and their practicability

Energy consultants need, as mentionned before, better tools, which

1) start with a reasonable detection of the air exchange conditions of a building,
2) set reasonable ventilation targets (mean, minimum, maximum values),
3) show different concepts to reach such targets,
4) and finally present tools to control the results of such retrofit actions.

These tools have to fulfill different conditions to be applicable for Swiss conditions:
Measurement methods have to be as simple and quick as possible, with well reproductible results;
By the fact, there is an interest to conserve energy in connection with ventilation without installing mechanical ventilation in all houses, such recomondations/laws would be more complicated as e.g. Swedish standards.
Pressurisation tests seem to be much more practical than tracer-gas tests for audit purposes. Target values considering wind class, exposure, use, building height and other parameters are missing up to now. Cheaper air change measurements sets may interest nevertheless.
Calculation methods for air change rates are available for consultants. Nevertheless we think, that grafical methods benefit of it's visualisation capacity; calculation models are exellent tools for research purposes.
Two concepts to control ventilation-rates in residential and institutional buildings made progress:

- The possibilities to controll ventilation by the occupants will be more efficient, if sensors indicate the necessity of additional air change (humidity -sensors, CO_2-sensors). - A recent report by Voss [16] gives a good background on the user behaviour; Steinert and Draeger [17] investigated the limits of humidity to prevent surface-condensation in corners, depending on the wall construction.

- If there should be higher safety in connection with the prevention of condensation and hygienic problems some type of additional mechanical ventilation is necessary also in cases of retrofitting.

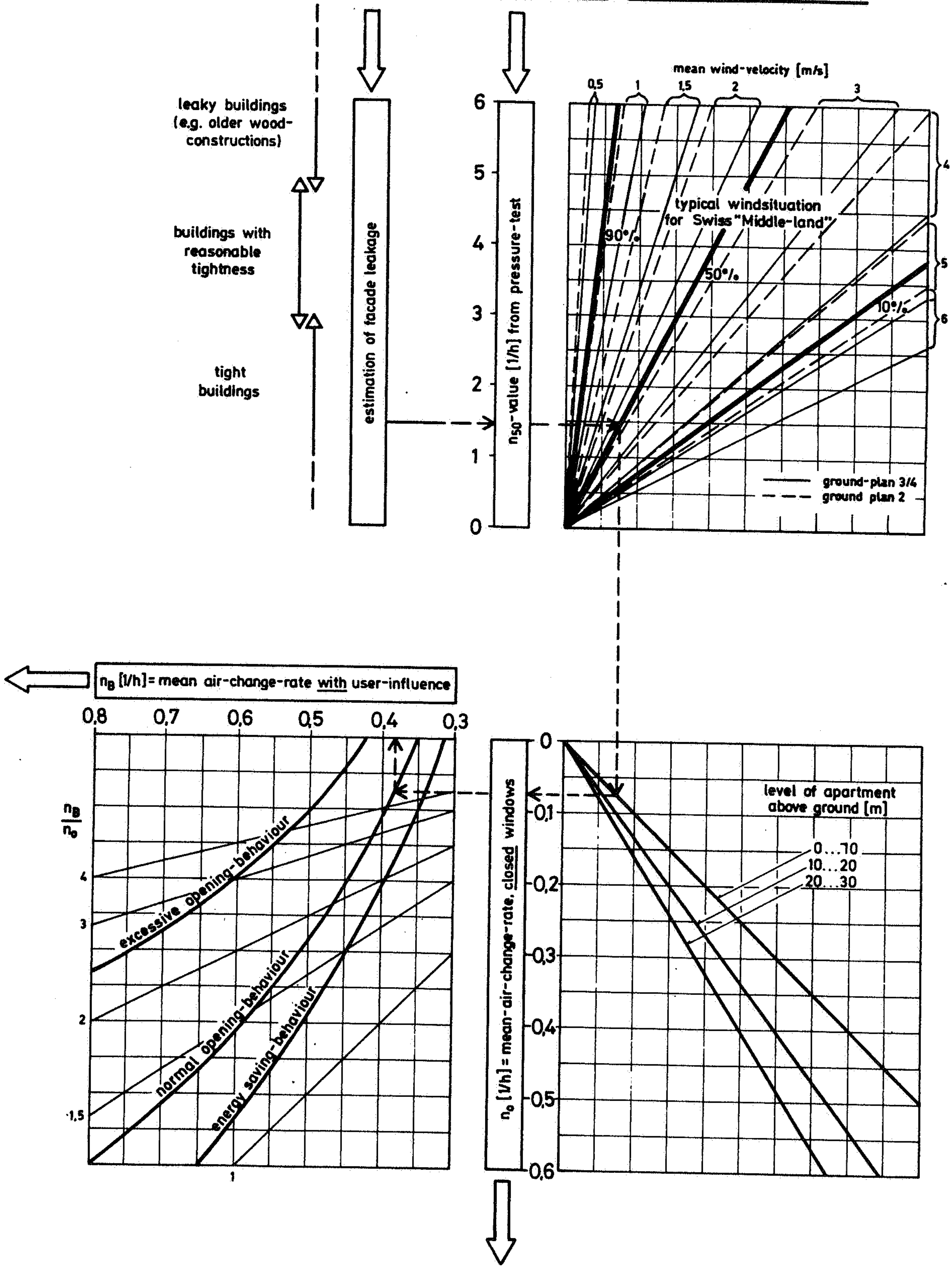
3.3 Grafical method to judge the air-exchange in residential builidings

The following tables are based on a calculation model, developped by Haerter, Steinemann [18]). Necessary input data for wind conditions have been developped by T. Baumgartner in connection with the Swiss design standard for heating plants. User factors, which are introduced into the calculation of the mean "occupied" air-changes, have their origine in Voss' report [16] and many observations of EMPA researchers [15].

The scope of this table, which is yet in draft form for one wind zone in fig.3, lies in the determination of the mean air change-rate. Depending on the reliability of the input data (building-shell leakage, user behaviour, exposure of a building within a wind zone) the result will have its accuracy.
Besides a mean air change, which is needed for the calculation of the mean winter energy losses, the table allows to check minimum wind conditions (condensation, maybe air contamination problems e.g. by formaldehyd) and maximum wind conditions (comfort problems).
As "extreme" conditions we have chosen the wind speeds, which is no more reached during 10 % of time, respectively which is exeeded during 10 % of time.

Fig. 3

Grafical estimation of mean air-change-rates in residential buildings (including extreme values)



Comments to figure 3 and 3a

- Symbols: n_{50} $[h^{-1}]$ = air-change $[h^{-1}]$ for a pressure difference of 50 Pa

  a_F = leakage of windows per meter of gap, calculated for 1 Pa $[m^3/h \cdot m \cdot Pa^{2/3}]$

  a_{RK} = leakage of roller-blind-cage per meter of cage width $[m^3/h \cdot m \cdot Pa^{2/3}]$

  ω = specific gap length for a window $[m/m^2$ of area$]$

  = $\ell \cdot A_F$; frequent value: 4 m/m^2

  ℓ = gap-length for a window [m]

  A_F = window area $[m^2]$

- Definitions

  ground plan 2: unit/dwelling with windows in (-- linie) 2 facades

  ground plan 3/4:
  (—— line) unit/dwelling with windows in 3 or 4 facades

  90 % line : for a certain wind zone this wind speed is not reached during 10 % of time; proposed value to check "minimum wind situation" with closed windows.

  10 % line : for a certain wind zone this wind speed is exeeded during 10 % of time; proposed value to check comfort conditions (drafts).

  User opening behaviour lines: these lines follow observations and recent experiments;

Limitations

- Extraordinary exposures of buildings should be taken into account by some extrapolation in the 2nd quadrant or by a change of wind class.
- All tables are designed for buildings with primarly natural air infiltration. For buildings with primarly mechanical systems these tables are not applicable.
  In cases with a small additional ventilator (e.g. in an internal toilet), this fan delivers a minimum air change in "closed conditions".
- Open chimneys and shafts may increase the air exchange remarkably. It is difficult to estimate this effects on existing Swiss experiments; corresponding experiments are made now.
  Extrem draft effects are not taken into account.

Fig.3a Estimation for buildings with primarly window infiltration (variation of fig. 3)

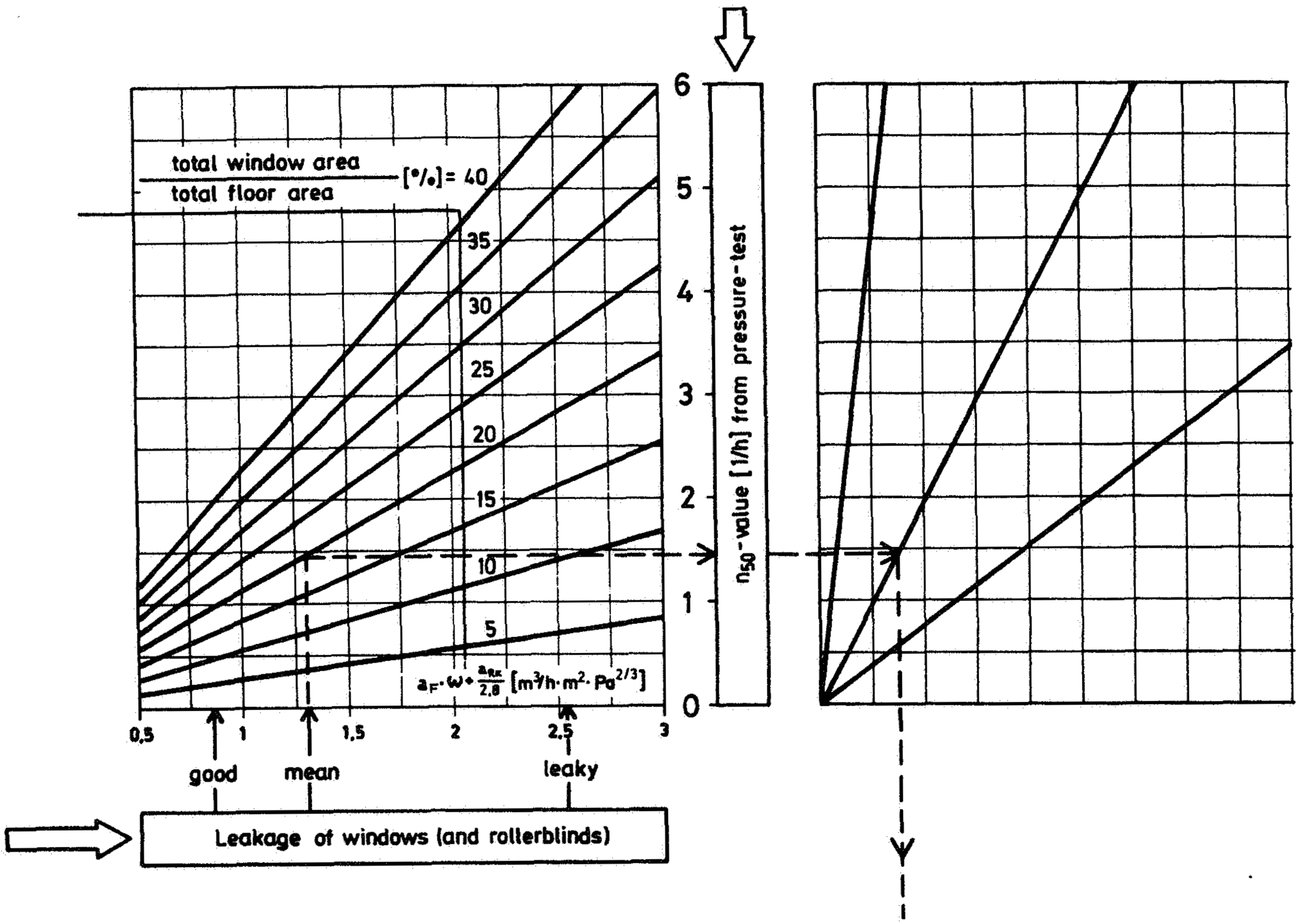


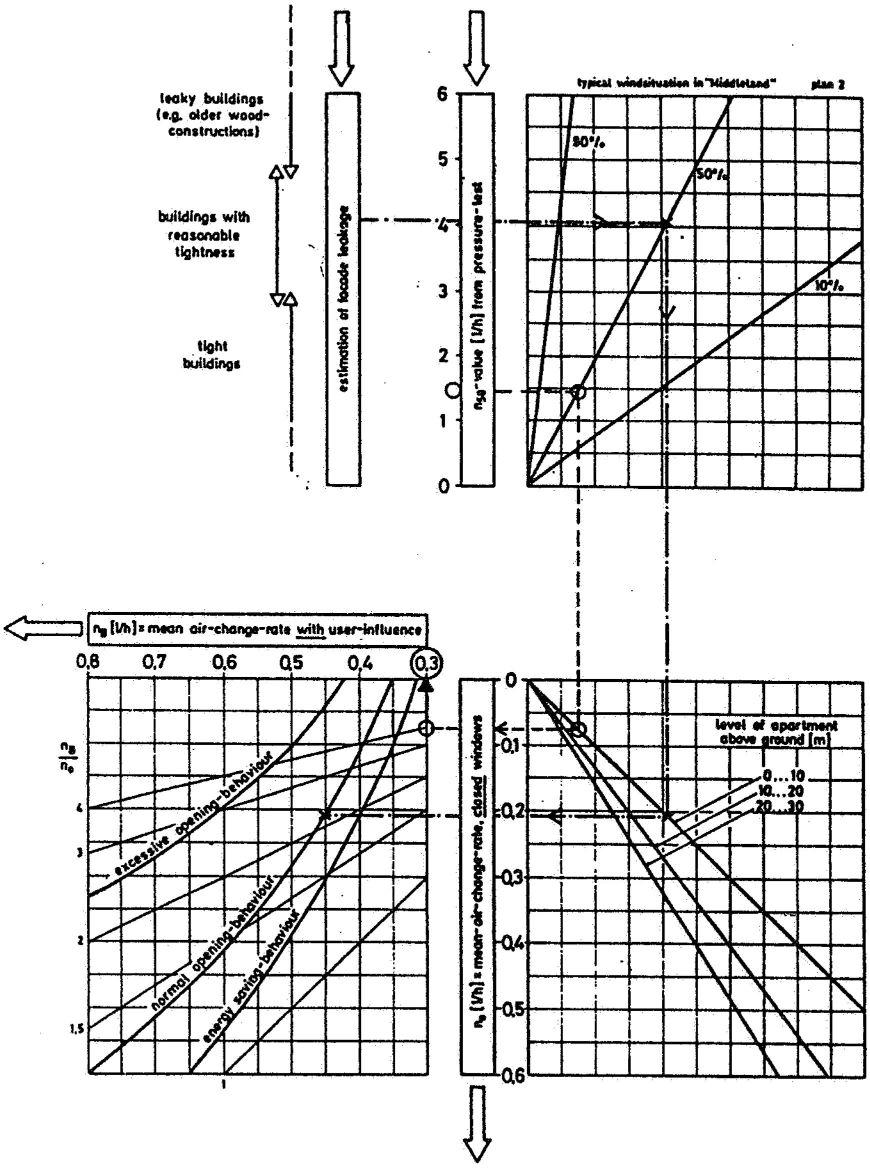
Figure 3a is adjusted to the situation, where infiltration primarly happens through windows, doors and maybe roller blind cages. The upper left corner of the figure 4 is replaced through a diagram, whereby window and roller-blind lekage data, the ratio of window area and floor area lead to an overall leakage.
Finally we explain the procedure of this estimation of air change for two examples in figure 4 :

Example 1 (x) without measured input data :

A consultant would like to estimate an actual air exchange rate, based on a short observation of a single-family-house (timber construction, no special complains about drafts). His estimation of leakage leads to the line of mean wind speed in the 2nd quadrant (middle land, normal exposure of the building).

The 10 m - line in the 3rd quadrant delivers a mean air change rate for closed conditions of 0.21 h^{-1}. The absence of indications on the user behaviour gives a vague indication of a real air change between 0.4 and 0.62 h^{-1} with a good probability for about 0.45 - 0.5 h^{-1}. A check of the "extreme lines" shows, that for low wind conditions and absence of the inhabitants there maybe an air change of only about 0.05 h^{-1}, in strong situations of > 0.5 h^{-1} (with preferably closed windows).

Fig. 4 2 Examples of air-change estimation



Example 2 (●)

In a second case this expert gets the possibility to measure the real building-leakage and the user-behaviour. Introducing these two values

- $n_{50} = 1,4\ h^{-1}$
- rare window openings

he is able to estimate the infiltration rates much closer.

4. CONCLUSIONS

As a consequence of the insufficient level of knowledge and an insufficient use of planning tools to reach air-change targets in retrofited buildings different actions are necessary:

- The establishment of audit-/measurement standards for air exchange (planned by Schindler-Haerter and EMPA as draft proposals)
- Additional research projects as experimental studies on the behaviour of advanced ventilation concepts for different building types, e.g.
  - for residential buildings
    - user controlled ventilation (with indicators)
    - user controlled ventilation with "add-on" mechanical systems
    - mechanical systems with heat recovery
  - for school buildings
    - user (teacher) controlled systems
    - mechanical systems with heat recovery
  - for office buildings
    - simple mechanical systems
      (research project ongoing by Sulzer, Winterthur)
- An establishment of target values for air exchange, which should be transformed to easy controllable values, e.g. leakage rates at 50 Pa or preferably lower pressures.

Fig. 5 gives details, how existing knowledge, combined with additional results from ongoing research could lead to target values and additional proposals for the application of certain ventilation control methods.

Figure 3 shows these possibilities graphically:
e.g. if there is a target value of 0.25 air changes in a small residential building (closed windows), this would be guaranteed by a building shell with a n_{50}-value of 5 h^{-1}. In this house there will happen minimum air changes of 0.05 h^{-1} and maximum values in the range of 1 h^{-1}. Depending on comfort demands, this situation may be unsatisfying.

It may be interesting to see, how important it is, to control certain target values in the buildings. Etheridge [17] shows the influence of workmenship in the leakage of nominally identical houses; some own tests on windows [8] show yet a wider spread of their leakage.
Coming target values should therefore be given with upper and lower limits of deviation; corresponding rules should fix the method and period of control (important e.g. for timber constructions).
These explanations show, that energy conservation efforts in connection with air change are not yet systematic. Many experiments demonstrate that not only constructional changes, but also other means as individual heat metering or a tight heating regime will promote these effects.

Figure 5 : Concept of building regulations to achieve controlled ventilation

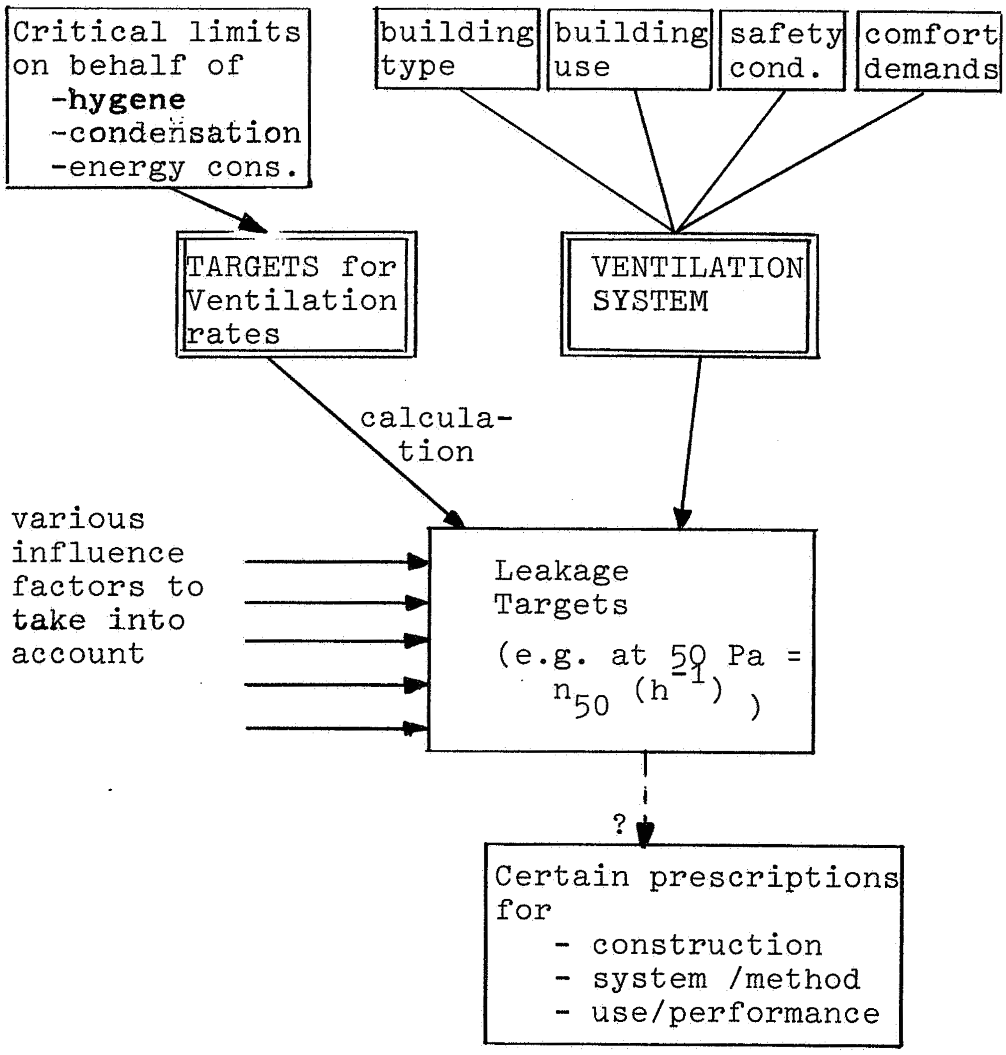
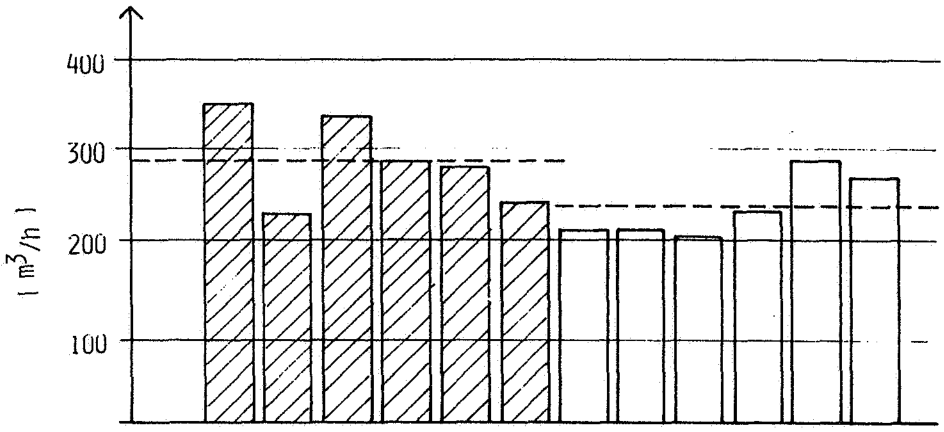


Figure 6 Dispersion of leakage for identical constructions

a) Leakage of nominally identical dwellings, 6 of them unoccupied (cited from Etheridge [18])



Occupied dwellings

n_{50} = 289 m³/h

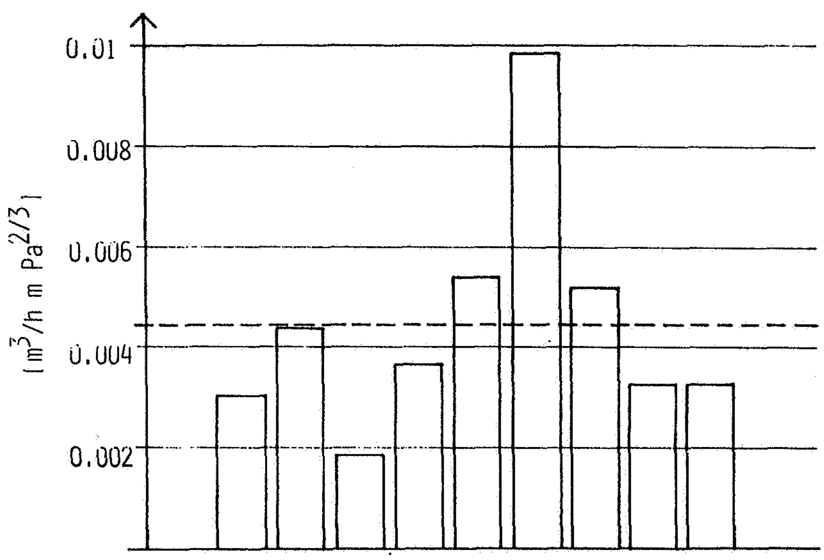
σ = 43.6 m³/h ≙ 15 %

unoccupied dwellings

n_{50} = 240 m³/h

σ = 31.5 m³/h ≙ 13 %

b) Leakage of windows with identical construction, but different size (see 8)



$\bar{a}$ = 0.045 m³/h·m·Pa²³

σ = 0.023 m³/h·m·Pa²³ ≙ 51 %

REFERENCES

1 AIC / ELMROTH, A. et al.
"Air Infiltration Control in Housing - A Guide to International Practice"
AIC/Swedish Council for Building Research, 1982.

2 GERTIS, K. and ERHORN, H.
"Super - Wärmedämmung oder Wärmerückgewinnung ?
Wo liegen die Grenzen des energiesparenden Wärmeschutzes?"
Bauphysik, Nr. 2, 1981, pp 50 - 56.

3 EMPA/VSSM/FFF/SZFF
"Besseres Lüften vermeidet die Kondenswasserbildung in Wohnbauten und besonders an Fenstern"
Zürich, 1981.

4 HALTINER, E.
"Abdichten bringt Gefahren und Probleme"
Schweiz. Spenglermeister- und Installateur Zeitung, Nr. 6, März 1980.

5 HARRYSSON, Chr.
"The Choice of Airtightness and Ventilation System for Single Family Houses"
AIR, Vol. 4, Nr. 3, May 1983, pp. 2-6.

6 WEGNER, J.
"Fazit: Überbelegte Räume"
(Untersuchungen des natürlichen Luftwechsels in Wohnungen mit sehr fugendichten Fenstern"
Sanitär- und Heizungstechnik, Nr. 12, 1982, pp. 857 - 860.

7 KRUEGER, W., HAUSLADEN, G.
"Zum Problem der Wohnungslüftung"
HLH 30, Nr. 11, 1979, pp. 425 - 431.

8 HARTMANN, P., MÜHLEBACH, H.
"Messprojekt Maugwil, Messdaten der Gebäudekonstruktion und des Energiehaushaltes"
EMPA-Report, Nr. 41643/1, Dübendorf, 1983.

9 HAERTER, A. and STEINEMANN, U.
"Messung von Lüftungsverlusten"
Experimental Research Project, Zürich, started in Dec. 1982.

10 BFK (Switzerland)
"Handbuch Planung und Projektierung wärmetechnischer Gebäudesanierungen"
Bern, EDMZ, April 1983.

11 PRESSER, G.S.
"Die neue ASHRAE - Lüftungsnorm 62 - 1981"
Klima-Kälte-Heizung, Nr. 4, 1983, pp. 179 - 182.

12 LUNDIN, L. and BLOMSTERBERG, A.
" An Antomated Air Infiltration Measurement System - it's Design and Capabilities - Preliminary Results"
AIR, Vol 4, No. 1, Nov. 1982, pp. 8,9.

13 SHAW, C.Y.
"Methods for Conducting small scale Pressurisation Tests and Air Leakage Data of multi - storey Apartment Buildings"
ASHRAE Transactions, 1982.

14 Kantonale Energiedirektorenkonferenz, Switzerland
"Grundsätze für Kantonale Energiepolitik; Plan für Vorschriften zur Reduktion der Wärmeverluste im umbauten Raum, über (u.a.) Lüftungs- und Klimaanlagen sowie Abluftanlagen"
Bern, 24.3.1983.

15 HARTMANN, P., BAUMGARTNER, T. and MÜHLEBACH, H.
"Forschungs- und Entwicklungsarbeiten mit dem Ziel einer kontrollierten Lüftung"
Documentation of 2nd Swiss Seminar "Wärmeschutzforschung im Hochbau",
Zürich-Dübendorf, Oct. 1982.

16 VOSS, K.
"Lüften und Heizenergieeinsparung"
Forschungsbericht F 1738 des Bundesministerium für Raumordnung, Bauwesen und Städtebau, Bonn, 1980.

17 STEINERT, J., DRAEGER, S. and PAULMANN, K.
"Eingrenzung der klimatischen Bedingungen für die Entstehung von Wandschimmel in Wohnräumen"
Gesundheits-Ingenieur, Nr. 2, 1981, pp. 57 - 67.

18 ETHERIDGE, D.W.
"Natural Ventilation in the U.K. and some Considerations for energy efficient Design"
3rd AIC Conference, London, Sept. 1983.

19 HAERTER, A. and STEINEMANN, U.
"Lüftungsverluste in Gebäuden; Berechnungsmethoden"
Report of research project (NEFF, Nr. 119), Zürich, Sept. 1981
(presented also in documentation 2nd Swiss Seminar "Wärmeschutzforschung im Hochbau, Zürich, Oct. 1982).

Attachment 1

OBSERVERFORM "WINDOW OPENINGS" in Residential Buildings

1 RULES / ADVICES

- Control - Time (day/week) to chose ....
- "Weighting factors" for windows

closed	0	point
small opening	10	points
rather open	20	points
wide open	50	points

- To chose 100 windows; to seperate out first all closed windows to treat than all openings.

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2 GENERAL DATA

- Location of building:
- Observed wall(s):
- Floors of observed windows:
- Heating system, type ...
- Control of set point of heating by:.....
- Thermostatic valves for radiators yes/no ?

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3 ACTUAL OBSERVATIONS

3.1 Time / day of week:

3.2 Weather:

- Wind : leafs quiet // little moving // branches moved // strong wind // storm
- Air temperature outside: .... °C
- Sun (before / now):
- Indications on room temperatures inside
  living room ... °C / sleeping room ... °C

3.3 Frequently open windows (certain rooms ?): ......
Nr. of probably "fixed" open windows (longterm openings) .....

3.4 Window openings: no. of "points" out of 100 windows =========