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Radon concentration in flats and its correlation with uranium content of building materials

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RESUMEN

Un estudio realizado durante 11 meses de radón en 25 departamentos de Wroclav, Polonia, permitió analizar las diferencias de niveles entre cada uno de ellos y las variaciones mensuales. A pesar de la existencia de cambios temporales significativos, se encontró que la diferencia entre los departamentos fue mucho más importante. Se encontró que la influencia del contenido de uranio en los materiales de construcción y su porosidad fue crítica.

PALABRAS CLAVE: Radón en interiores, gamma, espectrometría, uranio.

ABSTRACT

Radon monitoring in 25 flats in Wroclav, Poland performed for the period of 11 months enabled analysis of monthly and flat to flat variation. In spite of the existence of significant temporal changes, the difference among flats was found to be much more important. Influence of uranium content of the buidling material and its porosity was found to be critical.

KEY WORDS: Indoor radon, gamma, spectrometry, uranium.

INTRODUCTION

Radon monitoring has been performed in 25 flats and houses by means of KODAK LR115 detectors exposed for 1 month periods. Alpha tracks in the cellulose trinitrate layer of KODAK LR115 have been etched in hot Na(OH) and counted at the optical magnification of 100x Optiphot 2-Pol Nikon microscope.

Measurements have been repeated each month from March 2000 through February 2001. Data for November 2000 have been lost due to malfunction of the heater during chemical etching.

Gamma spectrometric measurements by means of GR-320 spectrometer with GPX-21A detector have been done in selected flats to determine radionuclides level in building materials.

Applied NaI(Tl) detector of 0.35 l volume worked with FWHM (resolution) better than 9% in the case of ^{137}Cs (663keV) peak, which was used as an internal calbration source. Analog to digital converter of 256 channel resolution and digital spectrum analyser resulted in 0.1 channel precision for this peak. At 10 minutes sampling time for ^{214}Bi 1760 keV peak within energy window 1660-1860 keV, about 550 gamma photons per 1 ppm of equivalent uranium concentration (eU) have been counted with uncertainity below 0.1 ppm eU.

The criterion for permitted radionuclides level in building materials in Poland according to the Institute of Building Technology (Instrukcja ITB nr 234, 1980) is described by the formula:

$$f_1 = 0,00027S_K + 0,0027S_R + 0,0043S_T \ ,$$

where S_K, S_R and S_T are the specific activities of K^{40}, Ra^{226} and Th^{232} (in Bq/kg) in the building material, respectively. Accepted value of f_1 should not be greater than 1.0 . Taking into account the radon risk, an additional parameter $f_2 = S_R$ has been introduced. Accepted value of f_2 should not be greater than 185 Bq/kg for Ra^{226} in the building materials.

In the case of the flat No 2, measurements have been done in 5 individual rooms.

Indoor radon concentrations combined with the gamma spectrometric results and data regarding the volume of rooms, enabled evaluation of:

emanation coefficient = Total ^{222}Rn of indoor air/Total ^{238}U of walls
radon flux= Total ^{222}Rn of indoor air / wall area

Obtained results have been evaluated by means of Excel and Statistica programs. The main point of interest was the differentiation betwen monthly variance and variance among flats. Means , standard deviations , and standard errors have been calculated for flats and months. ANOVA analysis has been performed (Davis 1986). Lowest Significant Differences (LSD) have been calculated both for flats and months using the formula:

$$LSD= t_{n-k,\_} (s^2(1/n_i+1/n_j))^{0.5}$$

$t_{n-k,\_}$ value of **Student** *t*
s^2 variance inside groups
$n-k$ degrees of freedom for s^2
n_i, n_j number of measurements in the i-th and j-th group

RESULTS

Average radon concentration in monitored flats was 57 Bq/m^3. Obtained results varied in the range of 17 to 214 Bq/m^3 (mean 57 Bq/m^3, standard deviation 28 Bq/m^3). Summmary of results is shown in Table1.

Radon concentrations in one flat (No2) were significantly outstanding during the meausrement period (max. 214 Bq/m^3; 11 - month average 137 Bq/m^3). It was mainly due to this flat that variation among flats was significantly greater than among months. However, only the flat No2 was distinctly different from other flats (Figure 1).

Differences among months were smaller and any single month cannnot be regarded different from others (Figure 2).

Table 1

Results of radon monitoring in 25 flats (Bq/m^3). Marked are greatest values each month

Flat No	March	April	May	June	July	August	Sept.	Oct.	Dec.	Jan.	Feb.	Mean
1	80	73	58	86	52	60	58	31	36	27	31	54
2	123	**182**	**147**	**122**	**134**	**170**	**103**	**214**	**116**	**109**	**86**	**137**
3	36	39	97	50	36	57	52	29	43	38	48	48
4	28	77	71	57	70	72	85	49	34	24	50	56
5	35	66	67	56	60	56	81	51	67	42	27	55
6	39	50	90	40	64	54	67	50	62	35	23	52
7	41	41	71	58	44	51	69	68	55	74	36	55
8	36	51	49	36	60	63	66	52	17	28	16	43
9	126	49	100	52	60	54	74	74	65	39	47	67
10	130	87	60	48	75	43	65	34	40	43	40	61
11	54	53	60	47	54	48	54	52	41	38	27	48
12	110	55	46	64	39	49	54	57	42	38	30	53
13		51	42	41	44	53	52	46	44	26	32	51
14	56	51	47	77	65	36	37	23	41	29	26	44
15	46	125	90	65	62	32	35	74	36	37	32	58
16	56	86	91	43	70	62	92	30	62	49	27	61
17	54	53	61	33	49	53	56	24	40	34	24	44
18	63	47	77	34	37	35	72	38	32	26	27	44
19	76	54	68	35	43	75	80	45	35	41	45	54
20	139	56	77	49	44	62	69	53	23	41	38	59
21	47	46	56	36	36	36	73	37	20	25	22	40
22	80	38	59	50	46	42	36	30	71	23	24	45
23	**144**	46	83	39	62	40	61	67	50	49	37	62
24	105	123	108	41	56	46	85	70	42	52	40	70
25	75	81	127	62	89	48	99	61	62	84	44	76
Mean	76	67	76	53	58	56	67	54	47	42	35	

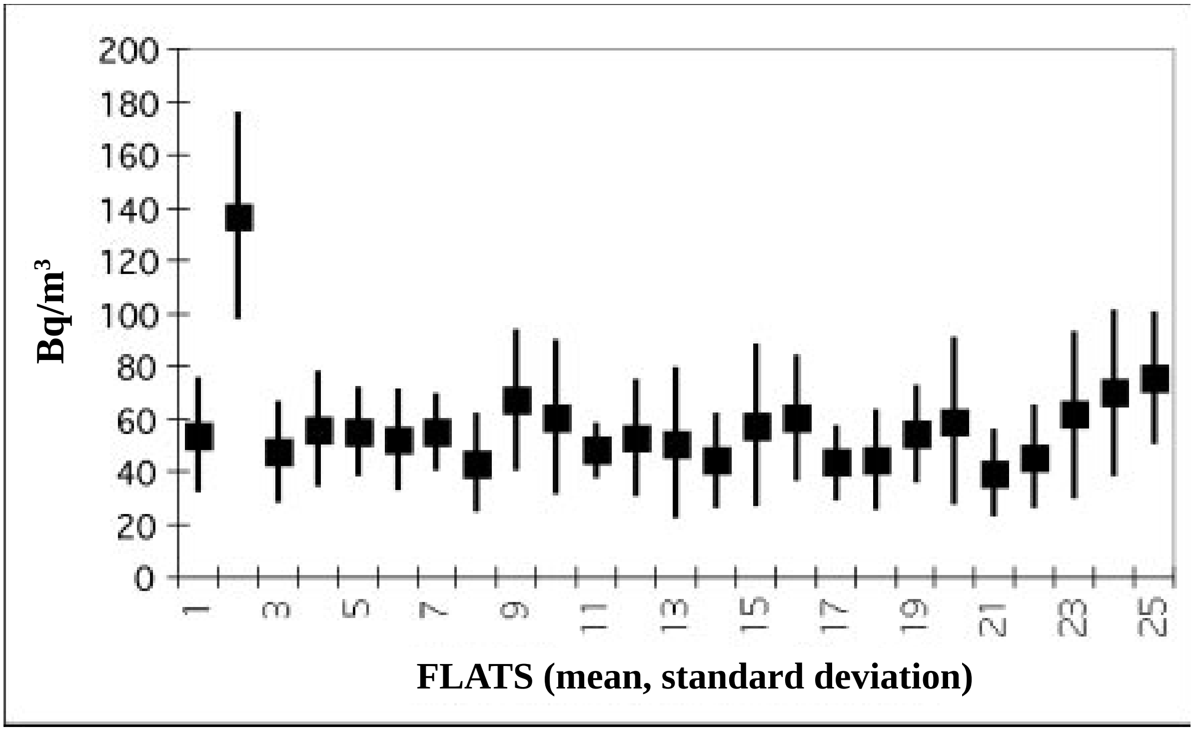

Fig. 1. Average radon concentrations for 25 flats.

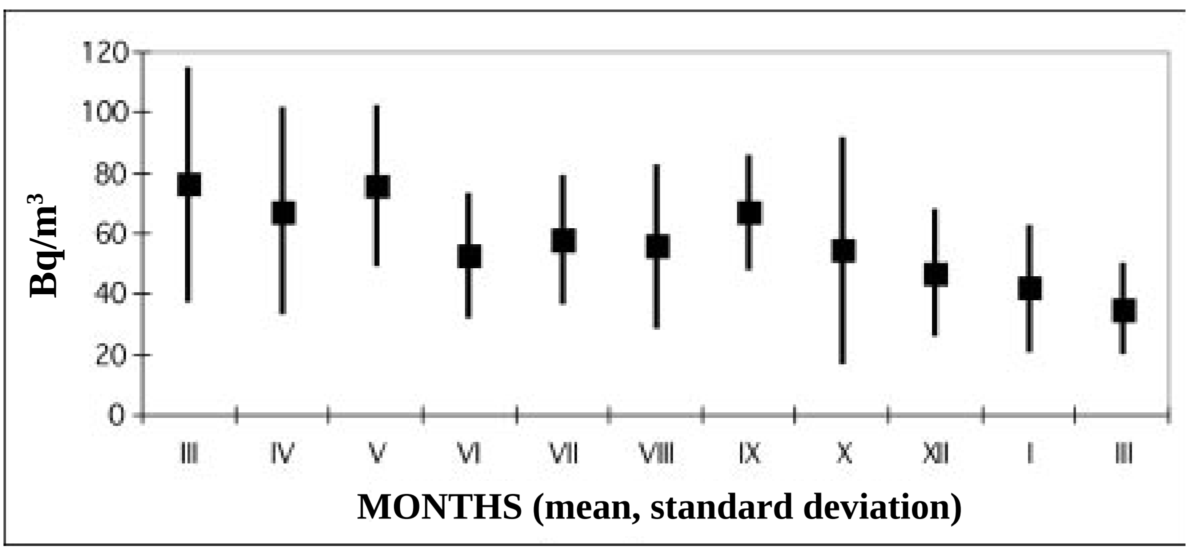

Fig. 2 Average radon concentration for 11 months (XI month is not included).

The reults of ANOVA analysis have shown that both variation among flats and among months were significant (Appendix I).

Differences among all measurements and Lowest Significant Difference (LSD) for months and flats have been calculated.

Ratio of every single difference (between flats or months) to the LSD has been chosen as useful presentation parameter and displayed in Tables 2 and 3. The greater the ratio the more outstanding the result was.

In the case of differences among flats only for two of them (No2 and No25) they were greater than LSD. In the

Table 2

Differences between flats and LSD ratio

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	mean
1	-	4,4	0,3	0,1	0,1	0,1	0,1	0,5	0,7	0,4	0,3	0	0,1	0,5	0,2	0,4	0,5	0,5	0	0,3	0,8	0,4	0,4	0,8	1,2	0,5
2	4,4	-	4,7	4,3	4,3	4,5	4,3	4,9	3,7	4	4,7	4,4	4,5	4,9	4,2	4	4,9	4,9	4,4	4,1	5,1	4,8	4	3,5	3,2	4,4
3	0,3	4,7	-	0,4	0,4	0,2	0,4	0,2	1	0,7	0	0,3	0,2	0,2	0,5	0,7	0,2	0,2	0,4	0,6	0,4	0,1	0,7	1,2	1,5	0,6
4	0,1	4,3	0,4	-	0	0,2	0	0,7	0,6	0,2	0,4	0,2	0,3	0,6	0,1	0,2	0,7	0,6	0,1	0,2	0,9	0,6	0,3	0,7	1	0,6
5	0,1	4,3	0,4	0	-	0,2	0	0,6	0,6	0,3	0,4	0,1	0,2	0,6	0,1	0,3	0,6	0,6	0	0,2	0,8	0,5	0,3	0,8	1,1	0,5
6	0,1	4,5	0,2	0,2	0,2	-	0,2	0,5	0,8	0,4	0,2	0,1	0,1	0,4	0,3	0,5	0,4	0,4	0,1	0,4	0,7	0,4	0,5	0,9	1,2	0,6
7	0,1	4,3	0,4	0	0	0,2	-	0,6	0,6	0,3	0,4	0,1	0,2	0,6	0,1	0,3	0,6	0,6	0	0,2	0,8	0,5	0,3	0,8	1,1	0,5
8	0,5	4,9	0,2	0,7	0,6	0,5	0,6	-	1,3	0,9	0,2	0,5	0,4	0,1	0,8	0,9	0	0	0,6	0,8	0,2	0,1	1	1,4	1,7	0,8
9	0,7	3,7	1	0,6	0,6	0,8	0,6	1,3	-	0,4	1	0,8	0,9	1,2	0,5	0,3	1,2	1,2	0,7	0,4	1,5	1,2	0,3	0,1	0,4	0,9
10	0,4	4	0,7	0,2	0,3	0,4	0,3	0,9	0,4	-	0,7	0,4	0,5	0,9	0,1	0	0,9	0,9	0,3	0,1	1,1	0,8	0,1	0,5	0,8	0,7
11	0,3	4,7	0	0,4	0,4	0,2	0,4	0,2	1	0,7	-	0,3	0,2	0,2	0,5	0,7	0,2	0,2	0,3	0,6	0,4	0,1	0,7	1,2	1,5	0,6
12	0	4,4	0,3	0,2	0,1	0,1	0,1	0,5	0,8	0,4	0,3	-	0,1	0,5	0,2	0,4	0,5	0,5	0,1	0,3	0,7	0,4	0,5	0,9	1,2	0,6
13	0,1	4,5	0,2	0,3	0,2	0,1	0,2	0,4	0,9	0,5	0,2	0,1	-	0,4	0,4	0,5	0,4	0,4	0,2	0,4	0,6	0,3	0,6	1	1,3	0,6
14	0,5	4,9	0,2	0,6	0,6	0,4	0,6	0,1	1,2	0,9	0,2	0,5	0,4	-	0,7	0,9	0	0	0,5	0,8	0,3	0,1	0,9	1,3	1,7	0,8
15	0,2	4,2	0,5	0,1	0,1	0,3	0,1	0,8	0,5	0,1	0,5	0,2	0,4	0,7	-	0,2	0,7	0,7	0,2	0,1	1	0,6	0,2	0,6	1	0,6
16	0,4	4	0,7	0,2	0,3	0,5	0,3	0,9	0,3	0	0,7	0,4	0,5	0,9	0,2	-	0,9	0,9	0,3	0,1	1,1	0,8	0,1	0,5	0,8	0,7
17	0,5	4,9	0,2	0,7	0,6	0,4	0,6	0	1,2	0,9	0,2	0,5	0,4	0	0,7	0,9	-	0	0,6	0,8	0,2	0,1	1	1,4	1,7	0,8
18	0,5	4,9	0,2	0,6	0,6	0,4	0,6	0	1,2	0,9	0,2	0,5	0,4	0	0,7	0,9	0	-	0,5	0,8	0,3	0,1	0,9	1,3	1,7	0,8
19	0	4,4	0,4	0,1	0	0,1	0	0,6	0,7	0,3	0,3	0,1	0,2	0,5	0,2	0,3	0,6	0,5	-	0,2	0,8	0,5	0,4	0,8	1,1	0,5
20	0,3	4,1	0,6	0,2	0,2	0,4	0,2	0,8	0,4	0,1	0,6	0,3	0,4	0,8	0,1	0,1	0,8	0,8	0,2	-	1	0,7	0,1	0,6	0,9	0,6
21	0,8	5,1	0,4	0,9	0,8	0,7	0,8	0,2	1,5	1,1	0,4	0,7	0,6	0,3	1	1,1	0,2	0,3	0,8	1	-	0,3	1,2	1,6	1,9	1,0
22	0,4	4,8	0,1	0,6	0,5	0,4	0,5	0,1	1,2	0,8	0,1	0,4	0,3	0,1	0,6	0,8	0,1	0,1	0,5	0,7	0,3	-	0,9	1,3	1,6	0,7
23	0,4	4	0,7	0,3	0,3	0,5	0,3	1	0,3	0,1	0,7	0,5	0,6	0,9	0,2	0,1	1	0,9	0,4	0,1	1,2	0,9	-	0,4	0,7	0,7
24	0,8	3,5	1,2	0,7	0,8	0,9	0,8	1,4	0,1	0,5	1,2	0,9	1	1,3	0,6	0,5	1,4	1,3	0,8	0,6	1,6	1,3	0,4	-	0,3	1,0
25	1,2	3,2	1,5	1	1,1	1,2	1,1	1,7	0,4	0,8	1,5	1,2	1,3	1,7	1	0,8	1,7	1,7	1,1	0,9	1,9	1,6	0,7	0,3	-	1,3

case of the flat No2 the difference was even four times greater than LSD.

In the case of differences among months only for four months (March, May, January, February) they were greater than LSD. But even the greatest average difference in the case of the February is only 1.7 times greater than LSD.

Gamma spectrometric results and f_1 and f_2 parameters of the building materials are presented in the Table 4. Equivalent uranium content of the walls of the flat No2 of maximum radon concentration was found to be significantly higher (3.5 ppm = 44Bg/kg) than the average value for other flats (2 ppm). Moreover, air-brick used for this house was of higher porosity than concrete walls of other flats.

Indoor radon concentration combined with gamma spectrometric results and data regarding the volume of rooms enabled evaluation of emanation coeffcient and radon flux which are presented in the Table 5.

CONCLUSIONS

Obtained results were in the same range as those obtained by CELOR (4- 600 Bq/m^3) average 38 Bq/m^3 (Turlo *et al.* 1997), and those obtained by means of Tastrak CR-39

Table 3

Differences between months and LSD ratio

M	III	IV	V	VI	VII	VIII	IX	X	XII	I	II	mean
III	-	0,6	0	1,6	1,3	1,4	0,7	1,5	2	2,4	2,9	1,4
IV	0,6	-	0,6	1	0,6	0,8	0	0,9	1,4	1,8	2,2	1,0
V	0	0,6	-	1,6	1,3	1,4	0,6	1,5	2	2,4	2,9	1,4
VI	1,6	1	1,6	-	0,4	0,2	1	0,1	0,4	0,8	1,2	0,8
VII	1,3	0,6	1,3	0,4	-	0,2	0,6	0,3	0,8	1,1	1,6	0,8
VIII	1,4	0,8	1,4	0,2	0,2	-	0,8	0,1	0,6	1	1,4	0,8
IX	0,7	0	0,6	1	0,6	0,8	-	0,9	1,4	1,7	2,2	1,0
X	1,5	0,9	1,5	0,1	0,3	0,1	0,9	-	0,5	0,9	1,3	0,8
XII	2	1,4	2	0,4	0,8	0,6	1,4	0,5	-	0,4	0,8	1,0
I	2,4	1,8	2,4	0,8	1,1	1	1,7	0,9	0,4	-	0,5	1,3
II	2,9	2,2	2,9	1,2	1,6	1,4	2,2	1,3	0,8	0,5	-	1,7

detectors calibrated in H.H. Wills Physics Laboratory, Bristol G.B (averages 70 Bq/m^3 and 136 Bq/m^3 for various flat groups) (Turlo *et al.* 1997, H. Pienkowska, J.Turlo 1997).

In spite of the significant differences among monthly values of radon concentrations, the differences among flats were much more important. Monthly variation could be explained mainly by meteorological conditions and ventilation of buildings. Variation among flats was a result of different building materials.

According to the current rules, the radon concentration of 200 Bq/m^3 is the maximum value which may be accepted in newly built flats. Only in one case this boundary value has been approached.

Obtained results indicate that relatively low uranium content of walls (being 4 times smaller than the permitted

Table 4

Gamma spectrometric results of K^{40}, Ra^{226} and Th^{232} content of building materials for selected flats.

Flat No*)	^{40}K %	^{238}U ppm	^{232}Th ppm	^{40}K (Bq/kg)	^{238}U (Bq/kg)	^{232}Th (Bq/kg)	f_1	f_2
1	1.9	2.2	6.5	576.5	27.4	26.7	0.34	27.4
2a	1.8	3.1	8.3	546.1	38.5	34.1	0.40	38.5
2b	1.9	3.2	10.9	576.5	39.8	44.7	0.46	39.8
2c	1.6	3.4	9	485.4	42.3	36.9	0.40	42.3
2d	1.6	2	5.6	485.4	24.9	23.0	0.30	24.9
2e	1.8	3.1	10.5	546.1	38.5	43.1	0.44	38.5
6	1.8	2	9.4	546.1	24.9	38.6	0.38	24.9
8	2.2	1.8	8.6	667.5	22.4	35.3	0.39	22.4
9	1.8	1.8	7.4	546.1	22.4	30.4	0.34	22.4
10	1.8	1.8	6.3	546.1	22.4	25.9	0.32	22.4
19	2	2	7.2	606.8	24.9	29.6	0.36	24.9
21	2.1	1.3	8.6	637.1	16.2	35.3	0.37	16.2
24	2.6	2.9	7.4	788.8	36.1	30.4	0.44	36.1
25	2.3	2	8.3	697.8	24.9	34.1	0.40	24.9

Table 5

Emanation coeffcient and radon flux of selected flats

Flat Number*	Total ^{238}U of walls [Bq]	Total ^{222}Rn of air [Bq]	Emanation coefficient [%]	^{222}Rn flux of wall Bq/m^2
1	178622	945	0.5	26
2A	**231031**	**4418**	**1.9**	**77**
2B	**238832**	**3161**	**1.3**	**55**
2C	**190925**	**1463**	**0.7**	**34**
2D	**306220**	**5040**	**1.6**	**43**
2E	**291892**	**4419**	**1.5**	**61**
6	**218076**	**1772**	**0.8**	**29**
8	**257242**	**1693**	**0.7**	**26**
9	**153451**	**2822**	**1.8**	**43**
10	**209736**	**1500**	**0.7**	**28**
19	**184499**	**1181**	**0.6**	**28**
21	**105608**	**700**	**0.7**	**19**
24	**599399**	**2349**	**0.4**	**25**
25	**192738**	**1744**	**0.9**	**40**

one) in the case of porous material may be responsible for radon concentration approaching the permitted indoor level (200 Bq/m^3). So, legally acceptable levels of radium/uranium in building materials being 185 Bq/kg may easily produce unacceptable indoor radon level.

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APPENDIX I

Analysis of variance as described by Davis (1986) has been applied to separate the total variance in a collection of mesurements into various components or sources. Total variance of the data set is broken into two parts - variance within each group and variance among groups.

Evaluation has been repeated for grouping in months and grouping in flats as well. Value of F test in both cases vere above the critical one so both sources of variation can be regarded as significant one.

FLATS	III	IV	V	VI	VII	VIII	IX	X	XII	I	II	Mean for flat	Variance within flat
	MONTHS												
1	80	73	58	86	52	60	58	31	36	27	31	54	426
2	123	182	147	122	134	170	103	214	116	109	86	137	1453
3	36	39	97	50	36	57	52	29	43	38	48	48	333
4	28	77	71	57	70	72	85	49	34	24	50	56	430
5	35	66	67	56	60	56	81	51	67	42	27	55	248
6	39	50	90	40	64	54	67	50	62	35	23	52	337
7	41	41	71	58	44	51	69	68	55	74	36	55	189
8	36	51	49	36	60	63	66	52	17	28	16	43	314
9	126	49	100	52	60	54	74	74	65	39	47	67	664
10	130	87	60	48	75	43	65	34	40	43	40	61	805
11	54	53	60	47	54	48	54	52	41	38	27	48	87
12	110	55	46	64	39	49	54	57	42	38	30	53	450
13	130	51	42	41	44	53	52	46	44	26	32	51	747
14	56	51	47	77	65	36	37	23	41	29	26	44	285
15	46	125	90	65	62	32	35	74	36	37	32	58	880
16	56	86	91	43	70	62	92	30	62	49	27	61	515
17	54	53	61	33	49	53	56	24	40	34	24	44	175
18	63	47	77	34	37	35	72	38	32	26	27	44	325
19	76	54	68	35	43	75	80	45	35	41	45	54	293
20	139	56	77	49	44	62	69	53	23	41	38	59	919
21	47	46	56	36	36	36	73	37	20	25	22	40	243
22	80	38	59	50	46	42	36	30	71	23	24	45	340
23	144	46	83	39	62	40	61	67	50	49	37	62	935
24	105	123	108	41	56	46	85	70	42	52	40	70	941
25	75	81	127	62	89	48	99	61	62	84	44	76	582
Mean for month	76	67	76	53	58	56	67	54	47	42	35		
Variance within month	1434	1109	664	389	425	691	333	1346	412	406	196		

Total variance = 810

Grouping in flats

Source of variation		Variance	Degrees of freedom	F = MS_A/MS_W
Among flats	MS_A =11 x Variance among means for flat	**3862**	**24**	**7,5**
Within flats	MS_W = Mean variance within flat	**517**	**250**	

Grouping in months

Source of variation		Variance	Degrees of freedom	F = MS_A/MS_W
Among months	MS_A =25 x Variance among means for month	**4417**	**10**	**6,6**
Within months	MS_W = Mean variance within month	**673**	**264**	

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