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Variations in indoor temperature in residential apartments of different size and building category

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SUMMARY:
In a case study, comprising 1177 residential apartments with 3248 rooms, temperature registrations every 15th minute in all living-rooms and bedrooms, during one year, in the system for individual metering and billing of space heating costs, were analyzed. The apartments were divided into two categories, apartment blocks from 1960th and row houses from about 1990. Apartments mean temperatures and standard deviations as a function of apartment size and category was compared. Corresponding was done on room level divided on apartment size for the two building categories. Finally, temperatures in bedrooms were compared to those in living-rooms for two objects from each category; presented in duration charts based on all single 15th minute values. The same pattern between different apartment sizes is kept for all month, though with a seasonal variation. The living-rooms are in mean warmer than bedrooms. The larger the apartments are the larger are the differences. The results provide a more nuanced picture of the temperature conditions in homes beneficial for better input data for building energy simulations.

1. Introduction

Knowledge of real indoor temperatures is important both in terms of thermal comfort and as the temperature affects the building's energy need for space heating. When performing simulations of the energy need in the design stage assumptions of what indoor temperatures the building will have must be done. To get reliable results it is necessary to use realistic indoor temperatures, an underestimation of 1°C give at least 5% error in the space heating need in Nordic climate. Both the absolute level and statistical measures of the variation of the indoor temperature are important to know.

Indoor temperatures in residential buildings have recently been studied by Pavlovas (2006), Bøkenes et al (2009), Yohanis et al (2010), Bagge et al (2011) and Kavgic et al (2012). Today's detailed knowledge of indoor temperature and its variations in different aspects, as dependency of apartment size, building age, time of the day, etc., in residential buildings is however limited. Bøkenes (2009) and Yohanis et al (2010) present detailed data for temperature variations between different rooms within apartments on Ireland. However, the habits in Northern Ireland do not agree with Scandinavian; the temperatures there are clear below what we can see in studies from Scandinavia. When looking at the residential building stock, it is of interest to know whether there are differences for example between rooms. People sometimes express a preference to have lower temperature in the bedroom. The type of homes and accordingly type of building technique may also be significant. Will the indoor temperature be different in older apartment blocks compared to newer row houses? Differences in plan, exterior surfaces and insulation level of the building envelope may imply different temperature and distribution. These are some objectives which this study strives to examine and gain increased detailed knowledge about.

In southern Sweden a housing company has implemented a system for individual measuring and billing of space heating costs (IMB) in about 3000 apartments, in size varying from one to six rooms. The method used for IMB is based on measurements of indoor temperature. The temperature is measured every 15th minute in all bedrooms and living-rooms. This provides a unique opportunity to investigate indoor temperatures, absolute levels as well as temperature distribution between rooms in different apartments.

2. Aims and objectives

The overall aim of this study is to investigate and present how indoor temperature varies between rooms in apartments of different size in multi-family buildings of mainly two types, apartment blocks and row houses, to give a more differentiated picture of the thermal climate in these types of buildings. A second aim is to contribute to more refined temperature data for energy simulations in apartment buildings.

3. Method and approach

In a case study of ten residential properties (here known as objects) with totally 1177 apartments and 85715 m² heated area, the temperature measurements, primarily used for individual metering and billing (IMB) of space heating costs, are analyzed from different aspects, mainly with help of Matlab.

3.1   Description of objects

Basic data for the ten objects this study covers are presented in Table 1. Nine of them are situated in the city of Lund in southern Sweden (55°42′N, 13°12′E) and one just outside. The climate in Lund (55°42′N, 13°12′E) is oceanic with relatively mild winters despite the northern location. Temperatures during winter are mainly around 0°C and summer 14-22°C; yearly precipitation approximately 600 mm, sparely as snow; prevailing wind direction W-SW.

The objects can, based on house type, be divided into two categories; apartment blocks (object 1-6) vs. row and semidetached houses (object 7-10). These two categories also represent two groups of age, the block houses are built 1963-1973, i.e. before the oil crisis, and houses in the other group are built during 1986-1995. Hence they are built according different building codes; the energy efficiency requirements got stricter step by step from 1973. Detailed information of building envelope construction was however not available. The apartment sizes in the first group are 1-4 rooms and kitchen with a total mean area of 69.3 m² and average room size of 26.2 m². The apartment sizes in the second group are 2-5 rooms and kitchen with a total mean area of 78.0 m² and average room size 26.6 m². More data about the studied building stock can be found in Dahlblom et al (2011).

The buildings are equipped with two-pipe hydronic heating systems with radiators. Nine objects are connected to district heating and the tenth has a natural gas fired boiler. Object 1-3 close to each other, share one substation, the other have one each and underground distribution pipes connecting the buildings in the object. The major part has exhaust ventilation systems with fans placed on the roof, two have balanced ventilation with heat recovery, see Table 1. The heating system was balanced and new thermostatic radiator valves were installed in all buildings before this study was performed. All buildings are subject to IMB of space heating. The set point indoor temperature is 21°C and the tenants can vary their indoor temperatures between 18 and 24°C with help of a thermostatic valve on each radiator.

TABLE 1. Basic data for the 10 objects.

Object number	1	2	3	4	5	6	7	8	9	10	Sum
Year built	1965	1965	1965	1973	1965	1963	1995	1989	1992	1986	
No of buildings	2	1	1	6	4	10	11	14	14	53	116
No of floors	2	9	9	2	3	3 – 4	1 – 2	2	1 – 2	1 – 2	1 – 9
No of apts	24	75	130	118	72	276	85	133	92	172	1177
- 1 RoK	0	21	31	34	0	28	0	0	0	0	114
- 2 RoK	2	7	29	41	18	48	22	56	37	74	334
- 3 RoK	9	25	68	31	36	144	34	46	35	53	481
- 4 RoK	13	22	2	12	18	56	26	22	10	36	217
- 5 RoK	0	0	0	0	0	0	3	9	10	9	31
No of rooms	83	198	301	257	216	780	265	383	269	496	3248
Heated area, m²	2096	5150	8017	7796	5908	19162	6705	10391	7786	12704	85715
Apt mean area, m²	87.3	68.7	61.7	66.1	82.1	69.4	78.9	78.1	84.6	73.9	72.8
Heating sup syst	DH/H	DH/H	DH/H	NG/S	DH	DH	DH	DH	DH	DH	
Vent type	EAH	EAH	EAH	EVS	EVS	EVS	EVS	EVS	BHR	EVS/ BHR	

DH = district heating, H = heat pump, NG = natural gas, S = solar collector, EAH = exhaust air heat pump, EVS = exhaust ventilation system, BHR = balanced ventilation with heat recovery.

3.2 Individual metering and billing of heating costs in the studied objects

The used principle for individual metering and billing (IMB) of space heating costs are based on achieved indoor temperature. The rent includes a "comfort temperature" of 21°C, for temperatures down to 18°C, tenants will be refunded and, vice versa, for temperatures up to 24°C tenants will be extra charged (LKF 2011). For the apartments in this study it will mean maximum of ±1200 SEK a year (135 € a year), to be compared with the mean rent 77000 SEK a year (8700 € a year) for the average apartment size.

3.3 Data collection and processing

The system for individual metering and billing of space heating registers indoor temperatures in all living-rooms and all bedrooms in the buildings. Thus, the number of sensors in each object is equal to the number of rooms in the object, see Table 1. The temperature sensor was calibrated during production to show a temperature reading with accuracy better than ± 0.15 °C (Sygel 2008). The temperature sensors are placed on internal walls, 3 – 4 m from the façade wall. They mainly measure the air temperature, but due to their position the difference between air temperature and operative temperature can be assumed to be small. Data from January until December 2010 was processed.

The system is supposed to register temperatures every 15th minute, which could have meant nearly 114 million readings for the studied period of 12 months. Unfortunately there have been data losses, partly due to interruptions in communication with the data server, partly due to scheduled interruptions during the summer. When communication is broken, the system inserts 21.0 °C, which leads to an overrepresentation of the temperature 21.0 °C. The retrieved data is processed by Matlab, excessive numbers of 21.0 °C readings are filtered and for shorter interruptions interpolated temperatures are inserted, longer are ignored. After this the available amount of data is 82 million temperature readings, i.e. 72 % average coverage over the year, and covering 79% of heating periods during 2010.

The living-rooms are generally about twice as large as the mean bedroom area, thus, when calculating apartment mean temperatures, living-rooms maybe should have been given double weight, which is not done here.

4. Results

4.1   Temperatures due to apartment size and building category

Figure 1 presents monthly mean indoor temperature and standard deviations for January-April and October-December 2010, i.e. months during heating periods, for varying apartment size divided on the two categories apartment blocks and row houses. Small variations in monthly mean temperature between apartments of different size can be observed, the same pattern is obtained for all months, e.g. apartment size 2 R&K in apartment blocks are always little colder than the others. The standard deviations do not differ much, but is somewhat larger for 5 R&K in the category row houses. There is also a seasonal variation, i.e. the indoor temperatures are not independent of outdoor temperature, and there are no cooling possibilities except free cooling by window airing.
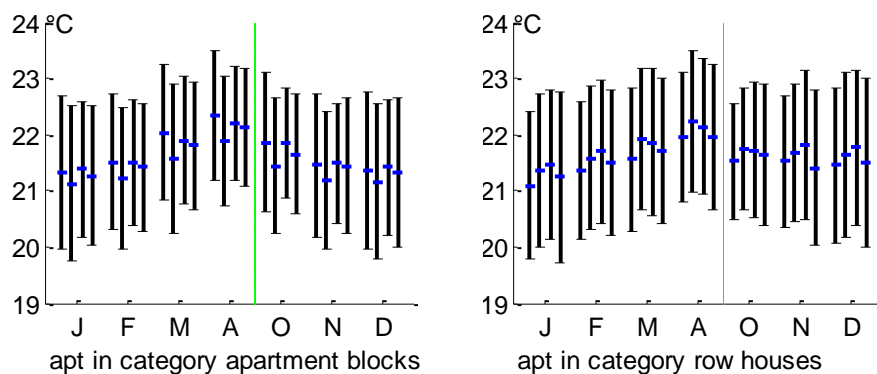

FIG 1. Monthly mean values and standard deviations for heating months on apartment level. Apartment size for category block houses are 1 R&K, 2 R&K, 3 R&K and 4 R&K respectively and for category row houses are 2 R&K, 3 R&K, 4 R&K and 5 R&K respectively.

4.2   Temperatures due to room type and building category

In Figure 2 and 3 the temperatures are further divided and, for the two categories, mean temperatures for living-rooms and bedrooms are separated. Broken down to room level, generally the living-rooms are warmer than bedrooms, the larger the apartment, the larger is maximal difference between living-rooms and bedrooms. About the same pattern can be observed in both categories and the pattern is kept for all month.

More detailed, on object level for apartment blocks, the mean values for the heating periods are between 21.3°C and 21.7°C with standard deviations in the range 1.11-1.34°C. Corresponding values on object level for row houses are mean temperatures between 21.5°C and 21.8°C with standard deviations in the range 1.22-1.40°C, i.e. objects in category row houses are warmer with larger standard deviations.
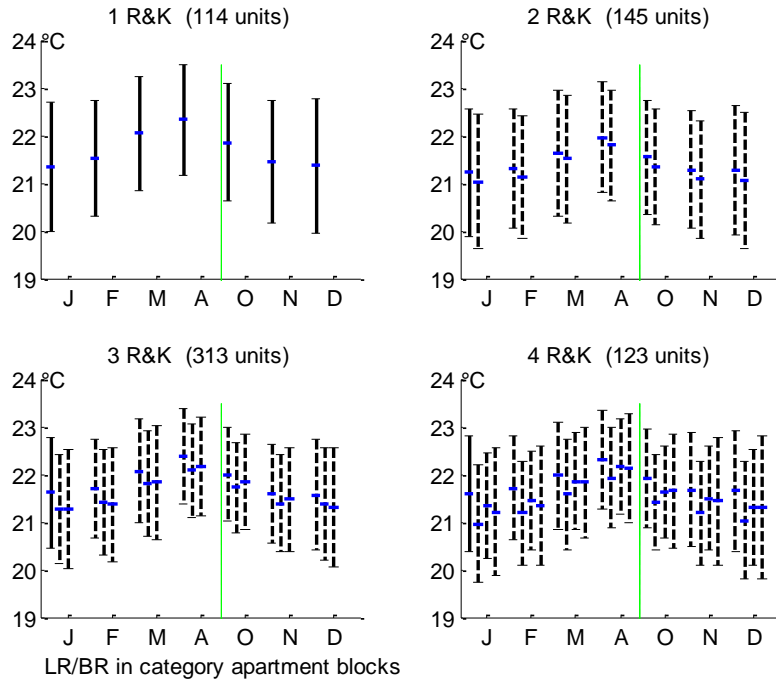
FIG 2. Monthly mean values and standard deviations for heating months on room level, divided on apartment size, for the category block houses. Solid lines are living-rooms, dashed lines bedrooms.
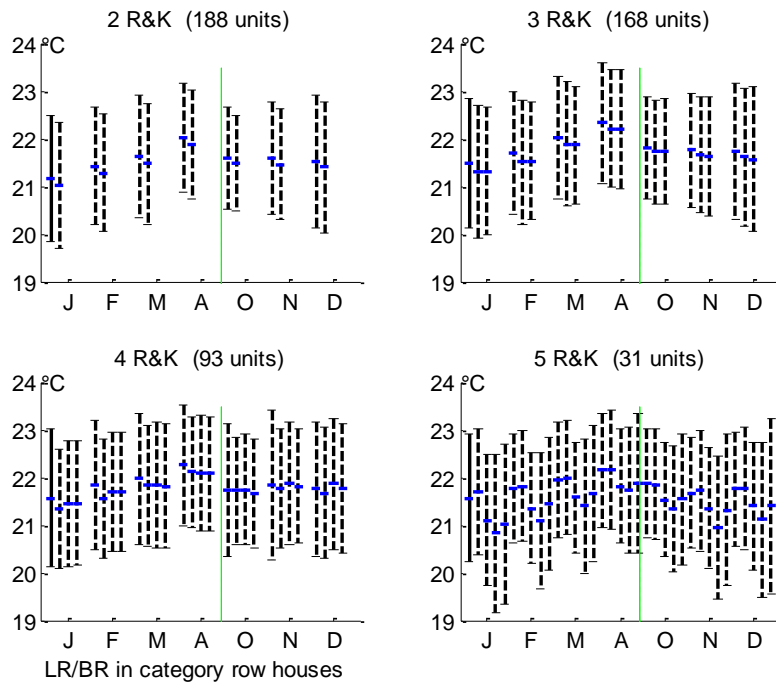

FIG 3. Monthly mean values and standard deviations for heating months on room level, divided on apartment size, for the category row houses. Solid lines are living-rooms, dashed lines bedrooms.

4.3   Temperature due to room type on object level

An even better overview of the differences between different rooms in apartments can be obtained from duration charts. Figure 4 – Figure 5 show, for two objects from each category, temperature differences between bedrooms and living-rooms, divided on apartment size. The scale on the x-axis is relative duration, i.e. compared to the total length of heating periods. The zero-line represents the mean temperature in the living-rooms in the object, the thick line represent the difference between mean temperature in living-rooms and bedrooms nr 1, the thin line d:o for the bedrooms nr 2, etc for broken and chain lines. The vertical lines show the breaking point when bedrooms mean temperature shift from colder to warmer than the living-rooms.

It can generally be noted that the temperature are lower in bedrooms, different bedrooms follow each other fairly well, with some exceptions, especially for larger apartments. Object 2 and object 8 are the two objects where the differences are largest, object 4 and 10 represent well the pattern in the other objects. Generally the differences are larger the larger the apartments are. From Figure 4 and Table 2 can for example be seen for object nr 2, apartment size 2 R&K that bedrooms nr 1 are colder than the living-rooms during approximately 35% of the heating periods (thick line). Accordingly, for apartment size 4 R&K, bedrooms nr 1 are colder during 94% of the heating periods, bedrooms nr 2 during 55% and bedrooms nr 3 during 27% of the heating periods (see Table 2). Remaining time the opposite situation is prevailing, i.e. bedrooms are warmer than living-rooms.

It is also possible to read out the largest differences in mean temperature, e.g. for bedrooms nr 1 in 4 R&K it is maximum 3°C colder, but only for a few hours. Temperature differences at 10th and 90th percentiles for the different bedrooms divided on apartment size and object are presented in Table 2, where also the relative duration for breakeven of bedroom and living-rooms temperature is reported. The temperature range between 10th and 90th percentile varies from 1.2°C to 3.1°C.
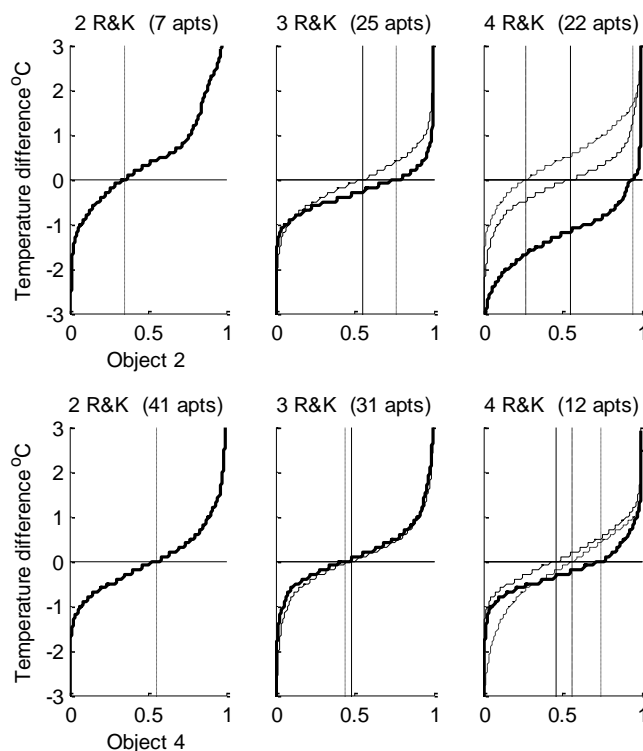

FIG 4. Duration for temperature difference between living-room and bedrooms; thick = bedroom 1, thin = bedroom 2 and broken = bedroom 3. Object 2 and 4, category apartment blocks.

2 R&K (55 apts)   3 R&K (46 apts)   4 R&K (22 apts)   5 R&K (9 apts)

Temperature difference °C

Object 8

2 R&K (74 apts)   3 R&K (53 apts)   4 R&K (36 apts)   5 R&K (9 apts)
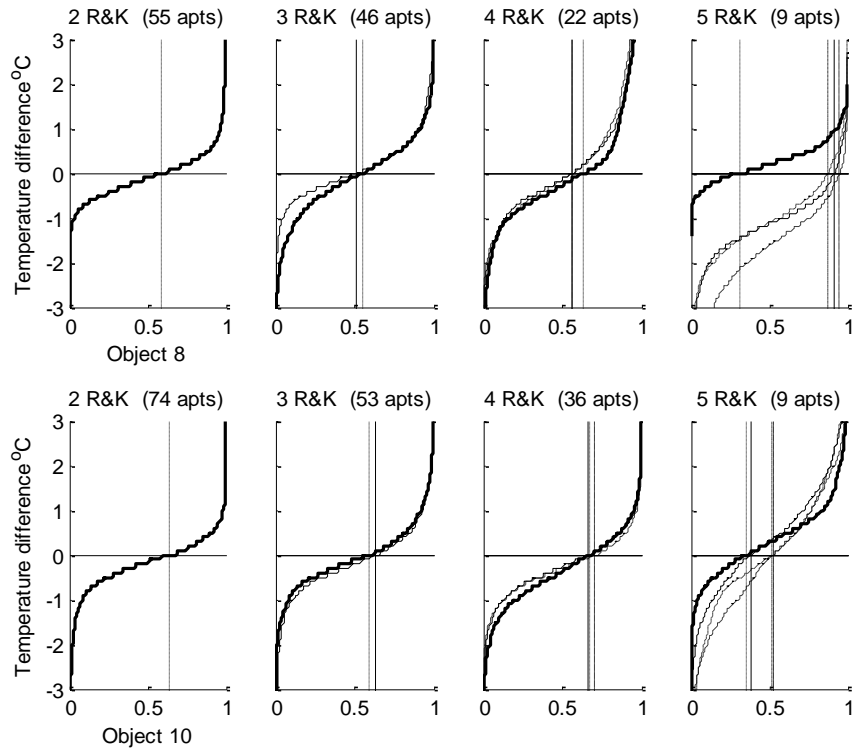
Temperature difference °C

Object 10

FIG 5. Duration for temperature difference between living-room and bedrooms; thick = bedroom 1, thin = bedroom 2, broken = bedroom 3 and chain = bedroom 4. Object 8 and 10, category row houses.

TABLE 2. Relative duration of equal temperature (dur_{dif0}) *and temperature differences at 10th and 90th percentiles* (ΔT_{p10} *and* ΔT_{p10}) *for bedrooms and living-room for different apartment size and object.*

size		2 R&K			3 R&K			4 R&K			5 R&K		
		dur_{dif0}	ΔT_{p10}	ΔT_{p90}	dur_{dif0}	ΔT_{p10}	ΔT_{p90}	dur_{dif0}	ΔT_{p10}	ΔT_{p90}	dur_{dif0}	ΔT_{p10}	ΔT_{p90}
obj	BR	-	°C	°C	-	°C	°C	-	°C	°C	-	°C	°C
2	1	0.35	-0.90	2.20	0.77	-0.90	0.30	0.94	-2.20	-0.30			
	2				0.55	-0.90	0.80	0.55	-1.00	0.80			
	3							0.27	-0.60	1.40			
4	1	0.55	-0.90	1.00	0.44	-0.60	1.00	0.74	-0.85	0.50			
	2				0.48	-0.85	0.90	0.46	-0.70	1.00			
	3							0.56	-1.40	0.80			
8	1	0.59	-0.70	0.50	0.55	-1.30	0.90	0.63	-1.30	1.80	0.31	-0.30	0.90
	2				0.51	-0.70	1.00	0.56	-1.20	1.90	0.92	-2.10	-0.10
	3							0.56	-1.30	2.30	0.95	-3.40	-0.40
	4										0.87	-2.20	0.20
10	1	0.64	-0.90	0.50	0.59	-0.90	0.90	0.67	-1.40	0.70	0.35	-0.70	1.30
	2				0.63	-1.00	0.80	0.66	-1.10	0.70	0.38	-1.20	2.20
	3							0.71	-1.10	0.50	0.52	-2.00	1.90
	4										0.52	-1.80	2.10

5. Conclusions and discussion

Based on the large data set it can be concluded that the indoor temperature for the category row houses are slightly higher than for category apartment blocks, though they have the same set point temperature, 21°C. The standard deviations are also slightly higher. In both categories apartment size 2 R&K has the lowest mean temperatures, all over the heating periods (Fig 2). Differences in mean temperatures between living-rooms and bedrooms, within apartments for all apartments in each category, are in the range 0.1°C – 0.5°C, larger for larger apartments (Fig 3).

The temperatures in bedrooms are generally below the temperature in living-rooms, but with large individual variations. The 10th percentile temperature difference is in the range -2.0°C to -0.6°C, with extremes on -3.4°C. Though the bedrooms are not always colder, the 90th percentile temperature difference is in the range 0.0°C to +1.9°C, with extremes on +2.3°C.

Only measuring one temperature in each apartment, as is done in some systems for IMB, may not give representative values. This study shows that deviations for single apartments in the dignity of 0.5°C, up to 0.75°C, can occur, if living-room temperature is used instead of apartment mean temperature.

The results can be beneficial as more refined temperature data for energy and moisture simulations in apartment buildings.

The floor plans and household size and composition are unknown and how these parameters affect the indoor temperatures have not been investigated. The fact that apartments of size 2 R&K have the lowest temperature may be explained by the number of person living in the apartment. Generally apartment of 1 R&K and 2 R&K are occupied only by one person, which means lower occupation density for 2 R&K, followed by lower heat gains from lighting, appliances etc.

6. Acknowledgements

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