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Preliminary Analysis of Indoor Temperatures and Humidity in Urban Social Housing

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Abstract. It is essential to create a comfortable and healthy indoor microclimate in order to assure proper conditions for work or recreation as people are spending 80-90% of their life in buildings. Therefore the building performance can help in achieving such sustainable living area, but also one should look into at other sources of temperature and humidity generators such as occupants' habits. Based on gathered data from observed apartments an insight into preliminary analysis of indoor temperatures and humidity in urban social housing is given. The analysis of the results confirm the set hypotheses that the occupants' habit significantly influence the indoor temperatures and humidity in urban social housing.

1. Introduction

Modeling sustainability is a difficult task as one needs to implement a large number of influences from both Earth and Human Systems as the systems are in continuous relationship [1]. The Earth System provides the sources of the inputs to, and the sinks that absorb the outputs of, the Human System. Unfortunately, most current models often solve a specific set of influences than a whole real system. This makes current models likely to miss important feedbacks in the real Earth-Human system, especially those that may result in unexpected and counterintuitive outcomes [2]. Therefore, it is important to incorporate all identified influences from both systems into the modelling processes.

Over the last two centuries the impact of the Human System has grown dramatically, becoming strongly dominant within the Earth System in many different ways. A group of researchers reported [2] that consumption, inequality, and population have increased extremely fast, especially since about 1950, threatening to overwhelm the many critical functions and ecosystems of the Earth System. Changes in the Earth System have important feedback effects on the Human System, with costly and potentially serious consequences. As the authors [2] argue that in order to understand the dynamics of either system the need to be coupled through bidirectional couplings representing the positive, negative, and delayed feedbacks that exist in the real systems.

The focus of this paper is on urban areas as a part of the Earth System where the Human System drivers are mostly focused on. Because of the expectation that the 60% of world population will live in urban areas by 2030 and that every day urban areas inhabit over 160.000 new citizens [3] it puts the tremendous importance on identification of residential environment assessment indictors for sustainable modelling of urban areas. Increasing population density in urban areas can significantly affect the quality of housing, as well as its sustainability from a long-term perspective [4–5]. Such occurs on a small scale as well and therefore it can be analyzed on a single household i.e. apartment. The urban social housing does not differ. Therefore, in the management of construction projects, special attention should be given to the planning as the most important phase of decision-making process and construction project management in order to achieve sustainable solutions in urban housing.

The aim of this paper is to show preliminary analysis of indoor temperatures and humidity in urban social housing as the result of conducted field research. These hygrothermal measures are the most important ones as they directly influence the occupants' quality of life, and it is important to adequately manage them in order to have sustainable and livable habitat. Having all stated in mind, the main hypotheses is stated: "The occupants' habits significantly influence the temperatures and humidity levels in urban social housing."

2. Research Background

The issues of quality of life in urban areas and therefore in urban housing, public i.e. residents satisfaction and sustainable development are the subjects of intense attention of researchers worldwide. The one of the major problems occur in the form of adequately measuring and evaluating residents' satisfaction with residential environment and/or sustainable development of urban areas. The variety of approaches results is identifying a various sets of indicators [4, 6–11]. On the other hand, various concepts for their evaluation and management have been developed concerning land [12–13], urban infrastructure [14], economic efficiency [15], and spatial management [16]. As the sustainability is the goal that construction professionals aspire to, in respect of the design, performance and impact of any given building, a various multi-criteria concepts have been developed is order to achieve sustainable decisions based on group consensus [12, 14, 16–19].

As the all aforementioned references deal with external factors and only indirectly reflect upon the indoor factors which can be controlled on an individual level (thermal characteristics of the building [20], quality of ventilation [21], quality of sound insulation [22], roofs [23], etc.). Another type of approach is dealing with materials and construction elements i.e. design strategies in order to improve thermal comfort in various housing projects [24–25] as well as the possible impact of temperature and humidity on the perception of indoor air quality [26]. Although dealing with indoor factors closely related to the specific apartment these factors are mostly of technical origin and does not provide any data about occupants' behaviors and habits.

The research conducted by Rudd and Henderson [27] gave slight insight into occupants' behavior as they monitored indoor moisture and temperature conditions in humid-climate residences in United States. During 4-year span they collected data in 423 houses (mix of standard and high-performance houses) located in various climate regions in order to understand when and why high humidity occurs. They concluded that in spite of various present air-extractor and humidity control systems one should combine different systems at the same time depending on humidity levels. Also, they briefly refer to differences in occupancy and occupant behavior but didn't make any connections between indoor air quality and occupants' behavior.

All aforementioned gave various insights into the problem of indoor temperatures and humidity in urban social housing, and how to cope with it, thus resulting into this research. In the following, the preliminary analysis of the problem is presented.

3. Research Design

3.1. Study area

This research aims to examine the temperatures and humidity levels in urban social housing and their connection regarding occupants' habits. Study area is located in the city of Rijeka in the area of Hostov breg where the first construction phase of social housing was erected during 2014 by the City of Rijeka's Social Housing Agency (APOS). The occupants were informed about the research and they all agree to be a part of research.

Firstly, the conducted interviews with APOS and the occupants has served the authors as a starting point for developing the project case (pilot study) with a goal to identify temperature and humidity levels and to give guidelines in order to reduce levels of humidity. Two apartments were selected for the pilot study. Both apartments are part of the same building and oriented in the same direction. The apartment's visualization is shown in Figure 1 together with locations where measurement instruments i.e. dataloggers (DL) were placed.

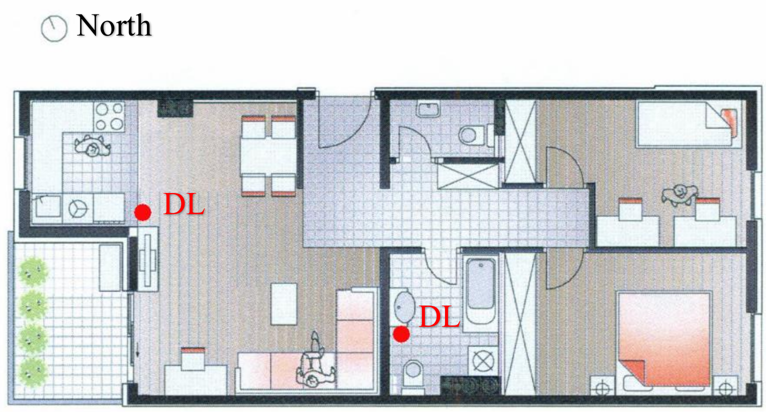

Figure 1. Datalogger positions in observed real estate.

The dataloggers were placed in two places where the most humidity is produced in an apartment – kitchen and bathroom. The data was gathered continuously during 6 weeks and the sampling rate was 1 minute. That resulted in gathering over 60,000 temperature and humidity readings by each datalogger and in total over 250,000 readings.

3.2. Establishing the model for humidity flow detection inside urban social housing due to occupants' habits

The proposed model for humidity flow detection inside urban social housing due to occupants' habits consists of several processes as shown in Figure 2. The proposed model starts with preliminary process of analyzing the Social Housing Agencies' real estate portfolio and selection of typical real estate. The selection can consist of one or more real estates. Such can be seen as initial process when the research problem is defined and the first interaction between the managers (APOS) and engineers (researchers and technicians).

This initial process is closely followed by detail analysis of selected real estate. During this process the data considering technical characteristics of selected real estate, its location characteristics as well as occupants comments about their apartment is taken into analysis resulting in complete real estate picture. Such is important and gives the researchers and technicians better insight during the identification of places in the real estate for datalogger installation. It is important to identify the correct place to put datalogger in order to collect the accurate hygrothermal data (temperatures and humidity). Once the installation places are identified the technicians can install the measuring equipment i.e. dataloggers into their positions. All aforementioned serves for the process of gathering hygrothermal data.

Depending on datalogger specifications and the duration of measurement period the gathering data intervals should be defined. Usually, datalogger can measure and store up to 16,000 relative humidity and 16,000 temperature reading over 0 to 100% RH and -40 to +70°C measurement ranges with selectable data sampling rate (2 s, 5 s, 10 s, 30 s, 1 m, 5 m, 10 m, 30 m, 1 hr, 2 hr, 3 hr, 6 hr, 12 hr, and 24 hr). Regardless various options and therefore storing capabilities, it is recommended to check the measurement instrument at least one a week and collect stored data. Such is especially important during lasting measurement periods. As the dataloggers at typically supplied with a long-life lithium battery, which can allow logging for one year, it can be considered to be satisfactory for conducting measurement in occupied apartment/apartments.

Once the data are gathered by the datalogger they can be easily exported to PC by adequate software. This is where the analysis of gathered data starts. But first, the gathered data should be exported from dataloggers software into txt-file or xls-file. Once the data is exported the analysis can be done by computing software such as Excel or Matlab. This analysis results in identification of specific i.e. characteristic event or trigger which can be used for modeling the spatial distribution of humidity inside observed apartment/apartments. For such computational fluid dynamics (CFD) analysis can be used to solve and analyze problems that involve fluid flows (in this case humidity and temperature).

Based on such numerical analysis the conclusions can be drawn resulting in guidelines for occupants.

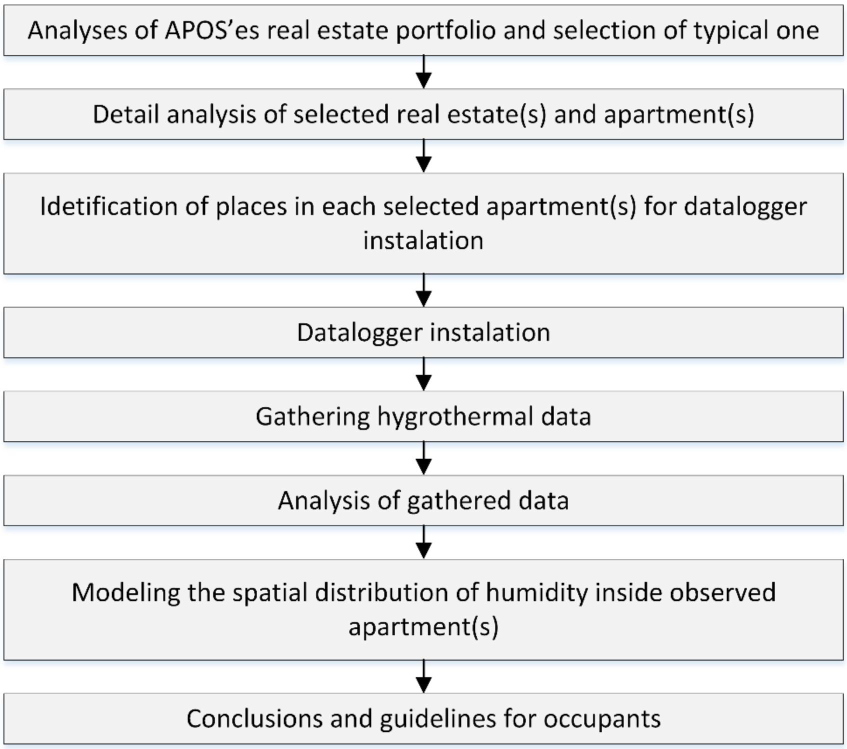

Figure 2. Model for humidity flow detection inside urban social housing due to occupants' habits.

The proposed model is based on the idea of combining different engineering expertise (civil engineering and engineering) whose synergy effect, as authors believe, can form a quality guidelines for new occupants in order how to deal with high humidity in their apartment as well as to inform existing occupants about their current humidity levels and to advise them if they have problem with humidity. All aforementioned is done to enable quality housing conditions and to improve quality of life in urban housing. Such is especially important when dealing with social sensitive population as the ones living in urban social housing projects.

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As the goal of the paper is to give preliminary analysis of indoor temperatures and humidity in urban social housing due to occupants' habits, the following section deals with two biggest generators of temperature and humidity in any household – kitchen and bathroom.

4. Results and Discussion

During the period of this pilot study (March and April 2018) the data was gathered in two apartments as part of the same social housing. As stated, apartments are oriented the same (towards North). General orientation of apartments is East-West and have openings (windows and balcony doors on the same side as can be seen in Figure 1).

Two dataloggers were placed in each apartment. The first one is placed in the kitchen area near the stove, while the other is placed in the bathroom near the sink (Figure 1). As the all technical elements of these apartments is the same, and the measurement was done during the same 6 weeks it is safe to assume that the dataloggers' readings show only the impact of occupants. The codification of dataloggers is presented in Table 1.

Table 1. Codification of dataloggers in selected apartments.

Apartmant	Kitchen	Bathroom
Apartment A – Hostov breg (no.17)	DL1	DL2
Apartment B – Hostov breg (no.5)	DL3	DL4

The result of the gathered hygrothermal data is shown for each datalogger during a single week. This is done due to large amount of collected data. Therefore, the relative humidity and temperature readings for the kitchen area is shown in Figure 3 (for DL1) and Figure 4 (for DL3).

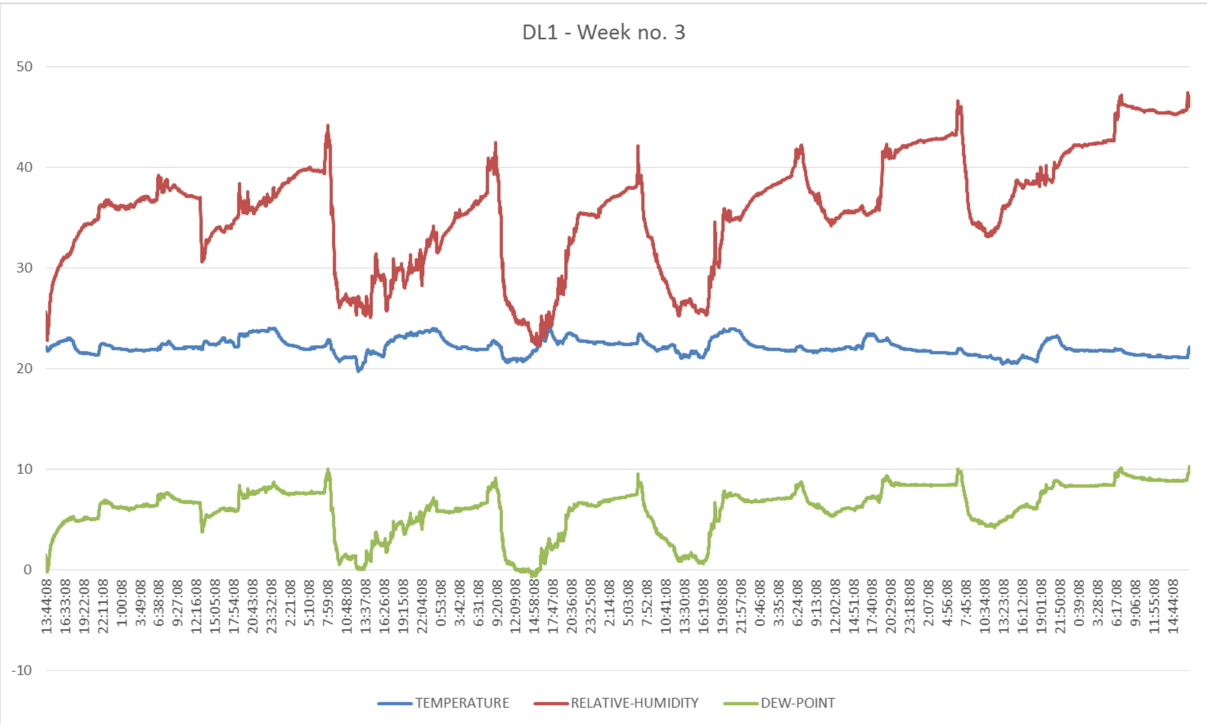

Figure 3. DL1 readings during week number 3.

The data gathered from DL1 during 3rd week of measurements shows rhythmic of daily behavior in the kitchen area of the Apartment A. The temperature fluctuate around 22°C with the minimum of

19.7°C and the maximum of 24.1°C. This results in normal average humidity level of 36.2%, almost on the boarder to be too dry (minimum is 22.2% and the maximum is 47.4%). As the average humidity in this room is normal the growth of humidity during day is continuous with quick discharges. One of the reasons for quick discharge can be the existence of window in this room.

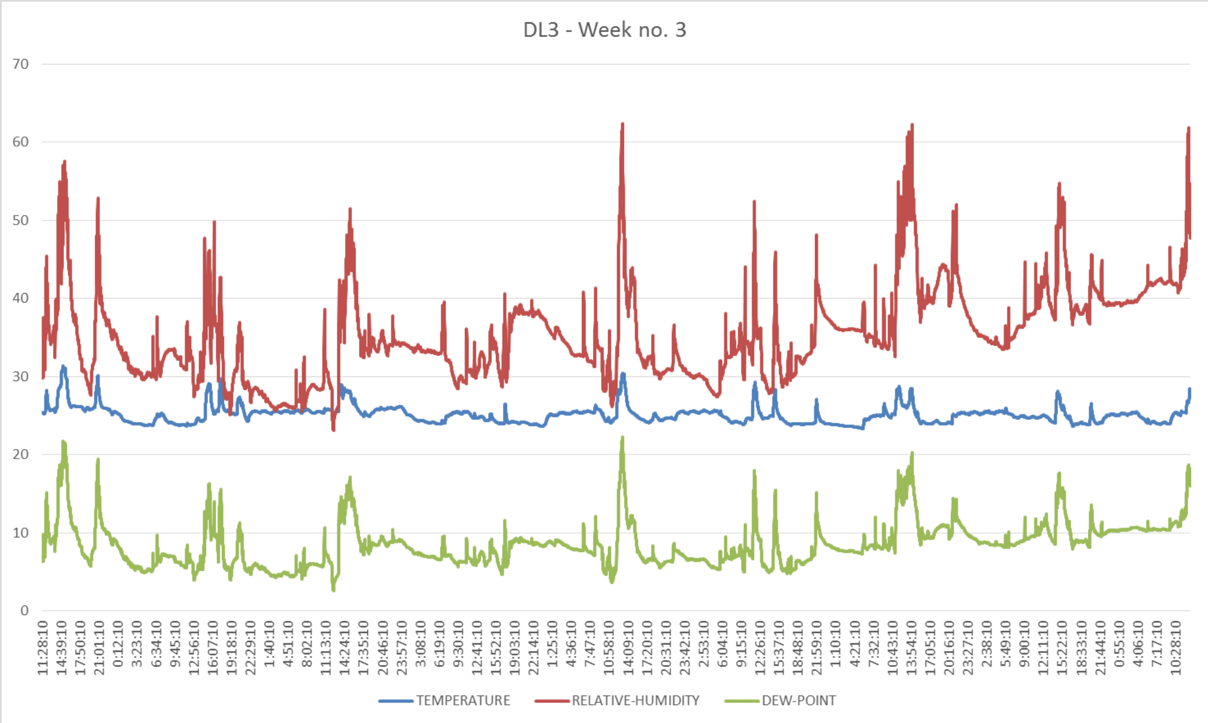

Figure 4. DL3 readings during week number 3.

The data gathered from DL3 during 3rd week of measurements shows constant activities of the occupants in the kitchen area of the Apartment B. The temperature fluctuate around 25°C with the minimum of 23.3°C and the maximum of 31.4°C. This results in normal average humidity level of 34.2%, almost on the boarder to be too dry (minimum is 23.2% and the maximum is 62.4%). As the average humidity in this room is normal the growth of humidity and discharges are rather fast during day. One of the reasons for quick discharge can be the existence of window in this room. Although, the accumulated humidity in this apartment is higher than in Apartment A.

The relative humidity and temperature readings for the bathroom area is shown in Figure 5 (for DL2) and Figure 6 (for DL4).

The data gathered from DL2 during 6th week of measurements shows rhythmic of daily behavior in the bathroom area of the Apartment A. The temperature is almost constant and slightly fluctuates around 22°C with the minimum of 21.7°C and the maximum of 23.6°C. This results in average humidity level of 51.8%, which is little higher than it should be (minimum is 33.3% and the maximum is 81.1%). As the average humidity in this room is little higher than it should be, the growth of humidity during day is concentrated in mornings and evenings as the rest of the day it discharges. One of the reasons for slow discharge is for sure the lack of window in this room, as the major discharge channel is through the bathroom room. Such should not be the practice as the discharge of humidity is only transferred from one room to another but not carried away from the apartment.

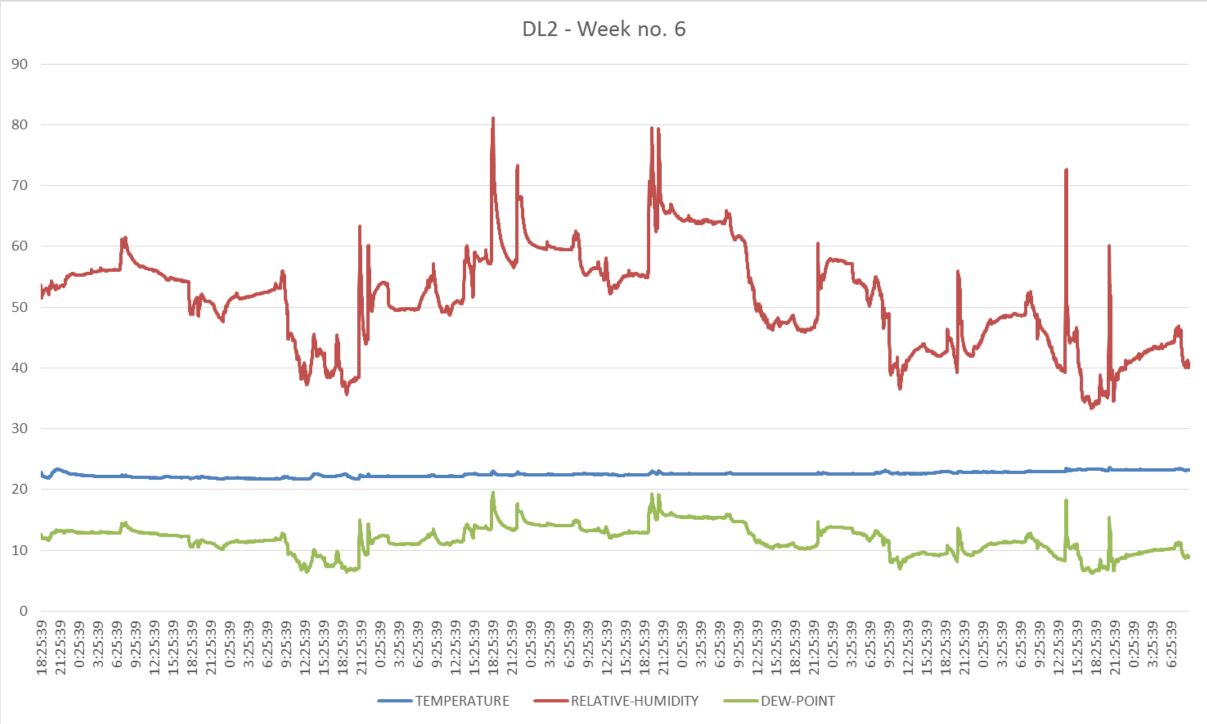

Figure 5. DL2 readings during week number 6.

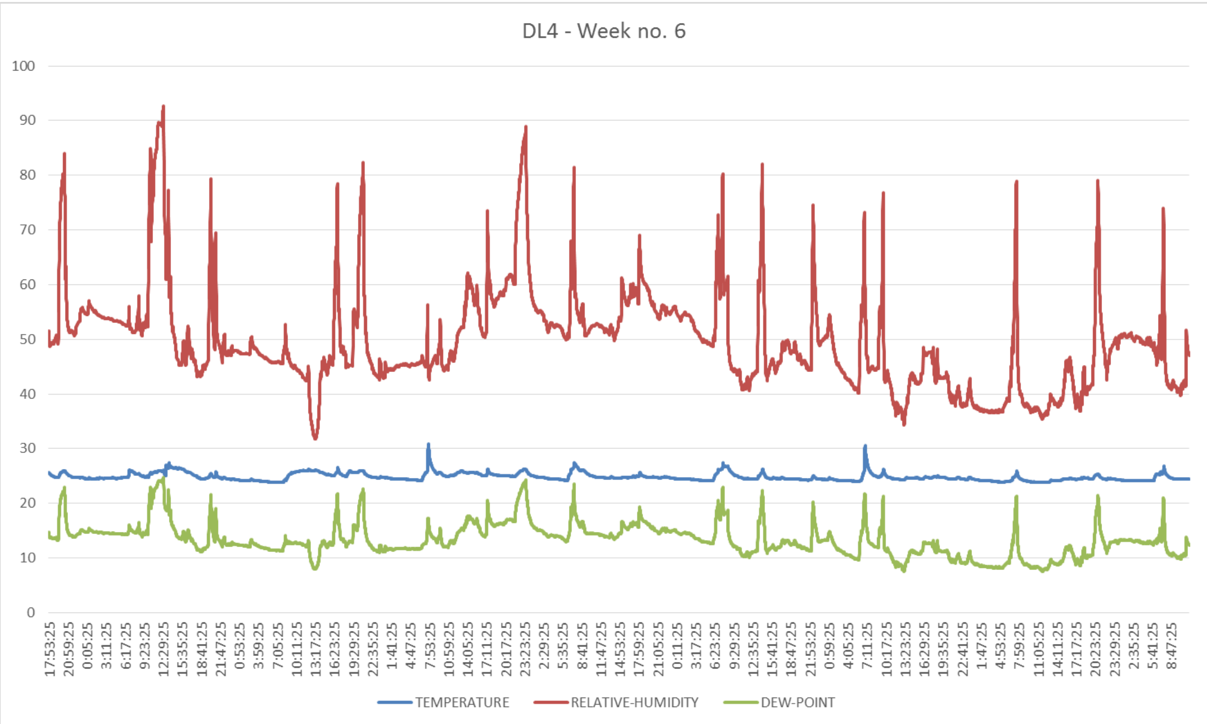

Figure 6. DL4 readings during week number 6.

The data gathered from DL4 during 6th week of measurements shows rhythmic of daily behavior in the bathroom area of the Apartment B. The constant activities of the occupants in this area is also visible thus resulting in a high peaks regarding humidity. This results in average humidity level of

48.3% with the minimum of 31.8% and the maximum of 92.8%. The temperature also varies a lot with the minimum of 23.8°C and the maximum of 30.9°C with an average of 24.6°C. As the average humidity in this room is almost normal, the growth of humidity is continuous during whole with the discharges periods during the night. One of the reasons for slow discharge is for sure the lack of window in this room, as the major discharge channel is through the bathroom room, especially during night. Such should not be the practice as the discharge of humidity is only transferred from one room to another but not carried away from the apartment.

Presented data give an insight into the differences between the temperature and humidity levels in these two apartments (A and B). It is evident that occupants' habits influence the temperature and humidity levels in urban social housing. There is a rather big difference between the temperature levels between the kitchen area of Apartment A (22°C) and Apartment B (25.1°C), as well as the bathroom area of Apartment A (22.5°C) and Apartment B (24.6°C). As the window is part of kitchen area the humidity discharge is rather quick during the whole day, which is not the case with the bathroom area.

As the bathroom area has approximately five time smaller volume than the kitchen area (kitchen is open to the living room) and the much frequent and larger use of hot water and/or rising temperature (such as showers, washing machines, etc.) the humidity discharge takes more time. One of the problems is the lack of window in the bathroom, which is common thing in this type of construction, and the installed ventilation system (air-intake ventilator) cannot cope with amount of humidity produced by the occupants.

The occupants often cope with this problem by opening the door with the expectation that the accumulated humidity will flow out from the bathroom. This is a slow way of discharging and also not the best one as the humidity is only transferred from one room to another but not carried away from the apartment. Therefore, the better way of dealing with this problem is to install any kind of air-extractor system such as home dehumidifier (either condensate of desiccant). These are portable electrical devices which reduce and maintain the level of humidity in the air on the comfort levels.

5. Conclusions

The presented preliminary analysis of indoor temperatures and humidity in urban social housing showed the influence of the occupants' habits on overall temperature and humidity levels in an apartment. This influence can rise up to level of high humidity which reflects into constant humidity saturation in apartments. Such should be avoided. Therefore the proposed model for humidity flow detection inside urban social housing due to occupants' habits is created in order to give guidelines for those households with high levels of humidity.

Differences among examined apartments were analyzed. As predicted, the biggest generators of temperature and humidity in any household are kitchen and bathroom. As the bathroom area are usually significant smaller than the kitchen area, usually opened to the living room, the humidity discharge takes more time. One of the problems is the lack of window in the bathroom, which is common thing in this type of construction, and the installed ventilation system (air-intake ventilator) cannot cope with amount of humidity produced by occupants. In order to cope with such problems and easily discharge the humidity surplus is to install any kind of air-extractor system such as home dehumidifier.

This preliminary analysis showed that the occupants' habits significantly influence the temperature and humidity levels in urban social housing. All gathered data will serve as input for computational fluid dynamics modelling in the future in order to make quality decisions for solving humidity problems in urban social housings in sustainable manner.

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