Proceedings of 10th Windsor Conference: **Rethinking Comfort**
Cumberland Lodge, Windsor, UK, 12-15 April 2018
Network for Comfort and Energy Use in Buildings, ht p://nceub.org.uk

Data collection methods for accurate spatial use within rooms.

Nick Van Loy[1], Ann Bosserez[2], Griet Verbeeck[3], Elke Knapen[4]

[1] Sustainability group, Faculty Architecture and Arts, University of Hasselt, Belgium, Nick.VanLoy@uhasselt.be;
[2] Sustainability group, Faculty Architecture and Arts, University of Hasselt, Belgium, Ann.Bosserez@uhasselt.be;
[3] Sustainability group, Faculty Architecture and Arts, University of Hasselt, Belgium, Griet.Verbeeck@uhasselt.be;
[4] Sustainability group, Faculty Architecture and Arts, University of Hasselt, Belgium, Elke.Knapen@uhasselt.be;

Abstract: Dwellings in Belgium are comparatively larger than residences in other countries and the occupancy rate of the living spaces is rather low. Both occupant presence and behaviour have a large impact on the actual energy consumption. Rooms are generally fully acclimatized while only part of them is used effectively which impacts the energy consumption of the dwelling.

This paper discusses spatial use within rooms and a methodology to monitor the effective spatial use of dwellings. Better insights in the effective spatial use can be used to increase the space and energy efficiency, e.g. by adapting the design of the house as well as the systems for heating and ventilation to the actual spatial use. In an in-depth case study, the spatial use patterns within three single family houses are monitored during 9 consecutive days in each season. During the monitoring period, a low cost, highly accurate, ultra-wideband, indoor localisation system was used to monitor the exact location of the residents within the dwelling. In addition, the temperature, relative humidity and light intensity in each room was recorded. Each hour, the residents were asked to fill in a survey on thermal comfort, activity and operation of windows or heating systems.

Keywords: Spatial use, Occupant behaviour, Use patterns, Sustainability

1. Introduction

With an average size of 124,3 m², dwellings in Belgium are larger than in other European countries (96,0 m²) (Eurostat, 2016). However, the size of a dwelling is not always in line with the actual occupancy rate. In 2013, 39% of the dwellings in Flanders were underused, while the size of only 57,8% corresponds to the effective occupancy rate (Vanderstraeten et al., 2016). In most dwellings, rooms are completely heated while they are not completely used most of the time or even not used at all. Additionally, research shows that 25% to 34% of the energy is used while a dwelling is unoccupied (Anderson et al., 2015). This causes an unnecessary high energy consumption and a large impact on the environment.

The Energy Performance of Buildings Directive (EPBD, 2002, EPBD, 2010) aims to improve the energy efficiency and to reduce the total energy consumption of buildings. It has been proven that these building regulations have been important in reducing the energy consumption of buildings by improving the building characteristics. However, when the energy efficiency of buildings increases, the behaviour and the presence of the occupants become a more important determining factor in the actual energy consumption (Santin, 2010).

Although the phenomenon of underused dwellings and their environmental impacts is known, there are only little insights into the effective spatial use in these dwellings. The energy efficiency of these dwellings could be increased if the building, as well as the installations for heating, ventilation and lighting, are better adapted to the effective use of the buildings. Therefore, accurate information on the spatial use is required. Current research (Ryu and Moon, 2016, Yang et al., 2016, Zou et al., 2017) is mainly focusing on occupancy and the level of detail is limited to presence or absence in a room.

In this paper, a methodology is proposed to study the spatial use within rooms more in depth, including circulation and activity patterns. When studying the occupant behaviour in relation to indoor climate and energy consumption, spatial use patterns and actions of the residents should be considered; these are discussed in Section 2. In Section 3, data collection methods to monitor the occupant behaviour in dwellings are presented. In an in-depth case study, the occupant behaviour in three single-family houses is monitored by using these methods. In section 4, these methods are evaluated for correctness and completeness of the output results, and for user friendliness for the residents. First results of the spatial use and behaviour of the residents are presented.

2. Occupant behaviour in relation to indoor climate and energy consumption

To investigate the occupant behaviour in relation to indoor climate and energy consumption, spatial use patterns of residents and their interactions with the building and its installations should be considered (Figure 1). The energy for space heating is directly influenced by the use of the heating system, the use of the ventilation system, the use of appliances and the occupancy of rooms, i.e. the number of rooms which are used and the number of people inside a room (Santin, 2010). Additionally, the behaviour of the residents is affected by external factors, such as the design of the building and its characteristics (Santin, 2010) and the outdoor climate. These external factors also influence the energy consumption.

In this paper, more factors are added (Figure 1) to the existing framework of Santin (2010). The occupancy patterns are combined with more detailed circulation patterns, which describe the exact location of the residents within a room, and activity patterns to get better insights in spatial use patterns and their impact on the energy consumption. Beside the energy consumption, the indoor climate is also affected by the occupant behaviour and the external factors. On their turn, the indoor climate will change the comfort experience of the residents which gives insights into the experience of the dwelling by the resident.

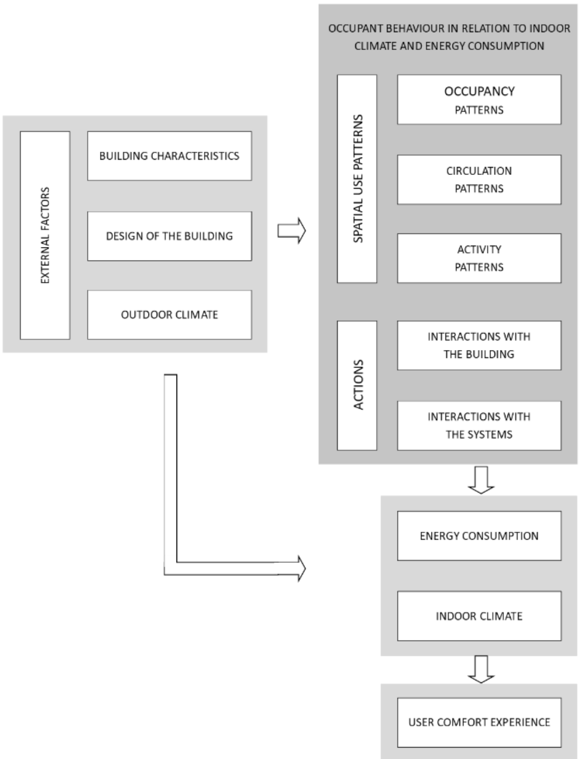

Figure 1: Impact of occupant behaviour on indoor climate and energy consumption based on the framework for occupant behaviour and energy consumption of Santin (2010).

Spatial use patterns

To determine spatial use patterns in buildings, three different patterns should be considered: occupancy, circulation and activity patterns. Occupancy patterns describe the presence or absence of residents in a room during the day. Because rooms are often heated while unoccupied, the energy efficiency of buildings could be improved by better aligning occupancy and heating patterns (Anderson et al., 2015, Santin, 2010). Circulation patterns give more detailed information on the exact location of residents within a room and throughout a dwelling and on areas or zones that are most frequently used. Because mostly rooms are completely acclimatized while only a part is effectively used, also here, there is an opportunity for improvement of the energy efficiency. Activity patterns which describe the activities of the residents during the day, such as cooking, reading, etc. are needed to get insights in the activity rate which affects the actions towards the building and its installations as well as the thermal comfort experience of the residents.

Actions

Residents' interactions with the building, e.g. by opening windows and doors, and their interactions with the technical installations, e.g. by adjusting temperature settings of heating systems, ventilations rate, opening or closing valves, have a direct effect on the indoor climate and energy consumption (Andersen, 2009).

Building characteristics and outdoor climate

Besides the spatial use patterns and actions, building characteristics, such as type of dwelling, construction year, insulation level (Guerra Santin et al., 2009), and the size of the dwelling and the number of rooms (Santin, 2010) are determining factors for the energy consumption in a dwelling. Additionally, local climatic and seasonal conditions play a prominent role in the energy consumption.

3. Data collection methods

Figure 2 shows a mixed-method methodology for measuring quantitative data on residents' location and actions and room temperature as well as qualitative data on thermal comfort and activities which impacts the indoor climate and energy consumption. Five different methods are used: an indoor localisation system, a smartphone survey, sticky notes, data loggers and documentation/interviews. These are discussed in the following paragraphs.

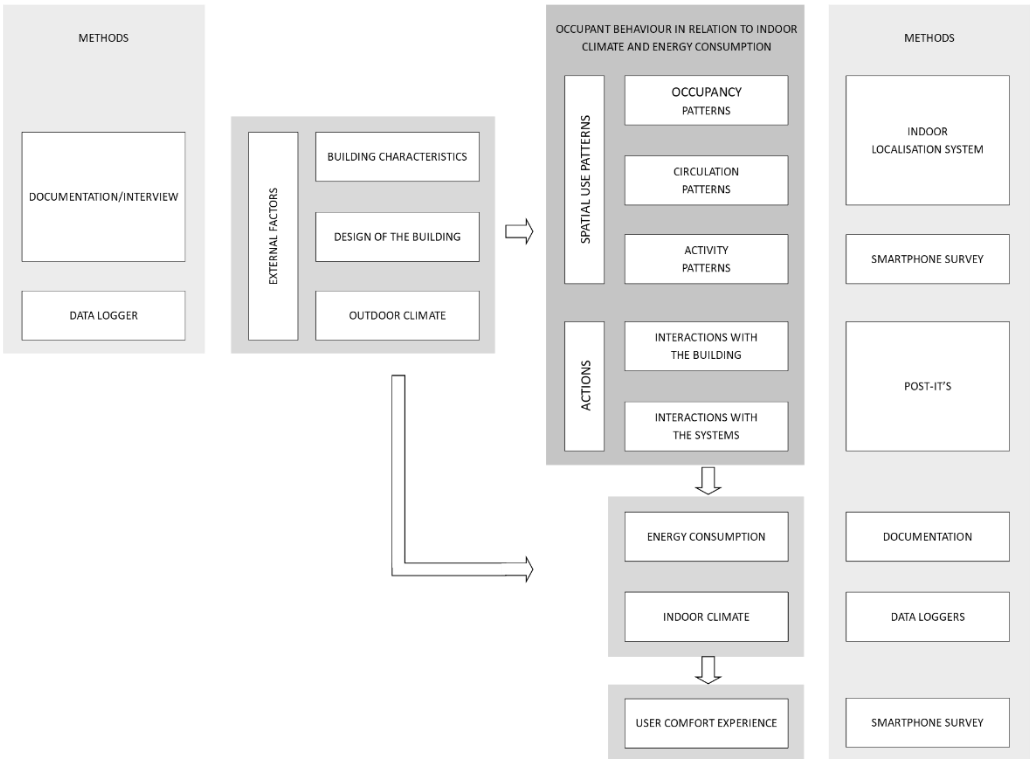

Figure 2: Methods which are used to monitor the occupant behaviour in relation to the indoor climate and energy consumption.

a. Indoor localisation system

Occupancy patterns, which only consider the presence or absence of residents in a room, can be measured by relative simple and low-cost techniques, such as passive infrared detectors or CO_2-concentration sensors in each room (Zou et al., 2017, Labeodan et al., 2015). However, to monitor the circulation patterns throughout a room or building and gain insights into the spatial use within the rooms, an indoor location system is needed which records the exact location of residents during the day.

Some boundary conditions and difficulties have to be taken into account when monitoring the indoor location of residents in dwellings. First of all, the monitoring system has to deal with a small, but very complex environment with lots of obstacles, e.g. indoor walls and furniture. In most situations, the system has to work in non-line-of-sight, where the direct signal is obstructed, and in a multipath environment, where the signal reaches the antennas (“anchors”) in multiple ways caused by reflection, these conditions can lower the accuracy dramatically, depending of the positioning algorithm that is used. Due to the small size of dwellings, the system has to be accurate enough (min. accuracy 1 m) because small errors in accuracy can lead to large errors in the results, such as presence in another room. In literature (Mautz, 2012, Alarifi et al., 2016), it is found that an ultra-wideband based system gives the best results in such environments.

For this research, a low-cost cost indoor localisation system, Pozyx (Pozyx, 2017), is used, which provides high accurate positioning and motion (accelerometer, gyroscope, magnetometer, pressure sensor) information, and is compatible with the open-source Arduino platform. The system consists of minimum four anchors (figure 3 $_{left}$) (for three-dimensional localisation), one tag for each resident (figure 3 $_{middle}$) and one master tag (figure 3 $_{right}$) to control and readout the data of the tags. The number of anchors needed for accurate localisation monitoring depends on the design of the building and it’s structure (walls, materials, e.g.) and has to be tested during set up. In general, 4 anchors are needed per floor, but the presence of f.e. dense walls results in a higher number of anchors to achieve the accuracy. Each person which has to be monitored, has to wear a tag. In case more persons have to be located at the same time, the tags have to be managed by one master tag. The master tags sends signals alternately to the different tags to initialize the localisation algorithm and to gather all the results.

For the ease of wearing, a case is designed (figure 3 $_{middle}$) which contains the tag, a battery, a charger and a switch. Residents can wear the case in two different ways: with a clip on a belt or with a lanyard. Theoretically, the autonomy of the tag is 18 hours, but this depends on different factors, such as the building layout, the building characteristics, etc..

Figure 3: modules to locate multiple persons. Anchor (left) with a fixed and know position, tag (middle) which has to be weared by the residents, mastertag (right) which manages the tags and gathers the location of the residents on SD.

b. Sticky notes

To monitor all residents’ interactions with the building as well as the interactions with the systems digitally, a lot of sensors would be needed. Therefore, pre-printed sticky notes are used (Figure 4) and placed on every window, door and heating element. Residents are asked to fill in the date and hour when they open or close the window or door to ventilate the dwelling. Interactions with the systems are only noted when the residents operate the valves of heating elements or when they change the thermostat settings. When a programmable thermostat is used, these settings are taken into account and residents only have to make a note when they make changes to the pre-set program.

Figure 4: Pre-printed sticky notes to write down the residents' actions

b. Data loggers

Data loggers onset Hobo u12-012 (onsetcomp, 2017) are used to monitor the indoor temperature, relative humidity and the light intensity. These data are collected with a 15-minute interval in each room which is used during the monitoring period. Data loggers must be located away from the windows to avoid the influence of the outdoor environment and they are placed on a height between 1-1,5m above the floor where people are living. The outdoor climate (temperature, relative humidity and light intensity) is measured at the same time as the indoor climate.

c. Thermal comfort survey

To qualitatively evaluate the thermal comfort of the residents, they are asked to fill in a survey. The survey is based on existing surveys on thermal comfort which consider the indoor temperature, relative humidity, air movement, activity level and clothing insulation of the residents (Guerra-Santin and Tweed, 2015, Wang et al., 2017, Kim et al., 2017, Wong and Shan, 2003).

Guerra-Santin and Tweed (2015) distinguish three different types of questionnaires: retrospective questionnaires (residents are asked about their comfort every week, month or year), real-time questionnaires (residents are asked about their comfort on the moment itself in the room where they are) and seasonal thermal comfort questionnaires (residents are asked about their comfort every season). With a retrospective questionnaire and a seasonal comfort questionnaire, it is possible to ask the comfort of the resident over a longer period and multiple rooms, but the resident might not be totally objective. The real-time questionnaire seems to be the most reliable and most accurate, because the resident has to assess his comfort at the moment itself and the answers can be coupled with the measured indoor climate data. However, this method is also the most time consuming. Therefore, in this research, a survey was set up as a "right here, right now" survey, which means that the residents have to fill it in on that moment and the place where they are at that moment (Manu et al., 2016).

The questionnaire consists of following questions:

- In which room are you?
- Which activity are you doing?
- How do you experience the indoor temperature at this moment?
- What type of clothes are you wearing?
- Do you have any comments on the indoor climate (air quality/air humidity/smell). If so, which?

The qualitative data of the survey are complementary to the data measured on location and indoor climate and can be coupled because the time is recorded as well. To accomplish a regular response rate, the residents received a SMS message each hour to remember to fill in the survey (Kim et al., 2017). It takes less than one minute to complete the questionnaire. The survey is available on an offline application on the smartphone of the residents, as it has to be possible to fill in the survey on the moment itself either when there is no internet available.

d. Interview/Documentation

The plans of the dwellings were collected to obtain insights into the design of the building and building characteristics, which were complemented with interviews to get insights into the use of the building by the residents. The residents have to fill in a short questionnaire with questions about themselves, e.g. their age, number of family members, their job, as well as their week schedule to get a first insight in their presence in the dwelling. Thereafter, they are interviewed about their use and experience of the building as a whole. During a subsequent walkthrough interview, residents provided insights on the function, use and experience in each room. The walkthrough interview allows the resident to clearly describe the use and experience of the room (Watson and Thomson, 2005).

4. Case study analysis

a. Description of the cases

The methods to monitor the occupant behaviour in relation to the indoor climate and energy consumption, which are discussed in this paper, are tested and evaluated by analysing the spatial use and energy consumption in three single-family houses. After each monitoring period, the methods are fine-tuned.

The three houses are large and under-utilized because only two residents are permanently living in the dwelling. Table 1 shows the main characteristics of the households and their dwellings.

Table 1: household and dwelling characteristics

	Dwelling 1	**Dwelling 2**	**Dwelling 3**
Household size (family size)	1	5 (3 children half-time inhabitants)	2
Occupation	Employed	Employed Self-employed 3 Students (absent from Monday to Friday)	Employed Employed
Type dwelling	Detached	Detached	Semi-detached
EPC*	496 kWh/m²year	Unknown	370 kWh/m²year
Surface (total/living)	167m²/89,3m²	396m²/204m²	217m²/140m²
Construction year	1990	Before 1945	Before 1945

(*the Energy performance coeficient shows how many energy a building is using. the score depents on the insulation level and installations but does not take the occupant behaviour into account. therefore this score can be different of the real energy consumption)

During nine consecutive days in each of the four seasons of the year, the spatial use, indoor climate and actions are monitored and the residents' activities and comfort experience are asked for with the methods described in Section 3. After each monitoring period, the data are evaluated on completeness and correctness by comparing the data with the insights gathered by the interviews. The residents are also asked to give feedback on the tasks they had to complete, such as wearing the localisation system, making notes of their actions and filling in the survey. Some results of the data analysis are presented in Section 4.c.

b. Evaluation of the data collection methods indoor localisation system

The raw data output from the indoor localisation system are X, Y, Z-coordinates with an ID- and time-stamp. These data need to be filtered because of errors when the signal between the tags and the anchors is too weak, which leads to inaccurate results, or when the residents are out of the system's coverage area, which mostly results in zero-values. When the filtered data are plotted on the floorplan of the dwelling, all locations where the residents have walked through or have been for a longer time, e.g. during an activity, can be visualized (Section IV.d).

During the monitoring period, the residents continuously have to wear the tag when being at home, which might be rather intrusive. After the first monitoring period, the tags were redeveloped and made smaller and lighter. During the second monitoring period, questions raised about the place where the residents had to place the tag when it was annoying to have it with them, e.g. while cooking. Problems about the autonomy showed up in the redeveloped tags, especially during the weekend when the residents typically spend more hours at home; they did not reach the 18 hours of autonomy as calculated and it took too long to reload the battery. A chest belt is provided, because some of the residents mentioned that the tag was difficult to wear in some situations, e.g. during cooking. In the future, the tracking system could be made smaller to make it less intrusive to the residents.

Sticky notes

The sticky notes are used to collect all residents' interactions with the building and the systems. Although sometimes the residents forget to fill in the sticky notes, they give a good and a detailed picture of the actions of the residents in the whole building.

So, only a few sticky notes were left after the monitoring period. After the first monitoring period, one of the residents explained that she changed her behaviour because of the sticky notes. For example windows that would be opened are now kept closed because of the time that needs to be invested in noting it down. This shows that it is important to interview the residents after the monitoring period and to ask them if and eventually in which way the data collection methods have changed their behavior during the monitoring.

Survey

Because only every hour a reminder is sent to fill in the survey, qualitative data on the experience of thermal comfort is only available on certain moments in certain rooms. However, the survey is mostly filled in in rooms where the residents are staying for a longer time and gives thereby a good insight in how the residents experienced the indoor climate. By increasing the frequency of reminders, more information could be collected, but it would be more intense for the residents with the risk of dropping out or non-response.

The residents have to install an application for the survey on their own smartphone, which is tested together with the residents and they can ask questions about aspects that are not clear to them. Although the survey is based on existing surveys, there were some questions about activities which were not specific enough for the residents and the possible choices of clothing were difficult to note. The residents need a smartphone because they have to fill in the survey on the moment itself. Some residents do not wear their smartphone with them the whole day, for them this is an extra effort. Remarks of the residents showed that too many reminders are sent (each hour), e.g. when they are not at home, but they can easily be ignored when these are unnecessary.

Data loggers

The data loggers are recording the temperature, the relative humidity and the light intensity every 15 minutes and are placed in the rooms used by the residents, which gives the opportunity to couple the indoor climate with the thermal comfort.

Overall feedback of the residents

During the feedback interview after each monitoring period, the residents mentioned that the period is intensive, but there was not one specific part which was the most intrusive for all residents. Some of the residents found the tracking system annoying, while for others the sticky notes were too time-consuming. Also the combination of wearing the tag for the indoor localisation system and their smartphone was very difficult.

c. Results of the data collection methods

The spatial use patterns in three dwellings and their impact on energy consumption and indoor climate are monitored during four seasons. As an illustration of the information that is gathered by the data collection methods, discussed in this paper, some results are presented here.

Localisation data

By plotting the localisation data as a heat map on the floorplan, the area of the room which is used and the places where the residents have been the most can be determined. Figure 5 shows a heat map of the localisation data of respectively resident 1 and resident 2 during one complete monitoring period. The dots are showing all recorded data. The colour changes from yellow to red when the density of the recorded data is higher. Both figures show that the room at the right-top is not really used, which corresponds to the description of the residents that this room is only used to open or close the windows. Also, differences in use between the two residents can be observed, e.g. the room at the right-bottom is especially used by resident 2, while resident 1 rarely comes in this room. The top part of the left-top room is also rarely used, which shows that the detail of the circulation patterns is relevant to analyse to indoor climate and energy consumption, in contrast to the occupation patterns which would mark the whole room as occupied.

Although a heat map shows the location of the residents throughout a certain period, this gives no insight in the zones where the residents stay the most. E.g. when the residents pass multiple times through the hallway, this gives the same result in a heat map as when the residents are staying on one place for a longer time. To determine the places within a room where the residents are staying, “stops” have to be defined. Based on literature (Cich et al., 2016), stops can be seen as locations where the residents are standing still for a longer time and these locations are related to an activity. In further research, insights in the residents’ activities in specific rooms will be derived from the survey and the interviews. These will be used to define stops and identify the zones where residents stay for longer periods.

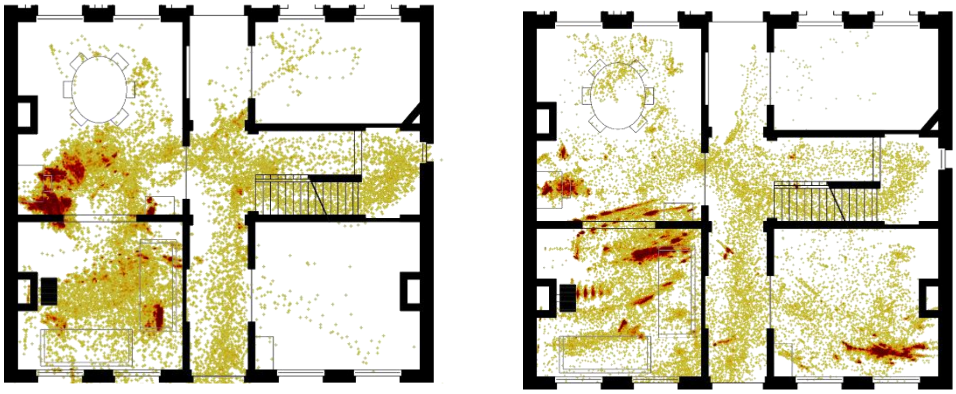

Figure 5: Spatial use of resident 1 (left) and resident 2 (right) on the ground floor of dwelling 2 during 9 consecutive days presented as a heat map

Combined data on occupancy, actions, indoor climate and comfort experience

Data on occupancy, actions, indoor climate and comfort experience of the residents are time-related and can be combined on a timeline for each room in the dwelling. Such a timeline (e.g. Figure 6) shows the occupancy of the room, if the room is heated and/or ventilated, the indoor climate of the room and the comfort experience of the residents. This combined timeline gives insights in how the room is used during a certain period and can be analysed to identify inefficiencies, e.g. when the room is heated while the room is not used or is only partly used. The comfort rating can be related to the actual indoor climate and the residents' interactions with the building or systems to change the indoor climate. In Figure 6, a timeline with data of a 3-day monitoring period in the office space of dwelling 2 is presented. It shows that the room is only used for shorter periods and is ventilated by opening the windows, even when the room is unoccupied. The heating is not used during this monitoring period (summer). As mentioned before, the thermal comfort rating is only collected at certain moments in time. During these 3 days, the resident only noted down once his thermal comfort. As he was comfortable in this room, he did not take any actions to change the indoor climate.

This timeline can be combined with the localisation data of the periods of occupancy which show the spatial use of the room in each of these periods. Five heat maps with localisation data of resident 2 are added to Figure 6: in heat map 2 and 4, the resident has only used a part of the room (at the book shelf and at the desk) while, in the first and the last heat map, the resident has used a larger part of the room. In heat map 3, the resident only stayed in the room for a short period of one minute. These combined data on localisation, actions, indoor climate and comfort experience, can be used to determine spatial use patterns and identify inefficiencies in energy and spatial use.

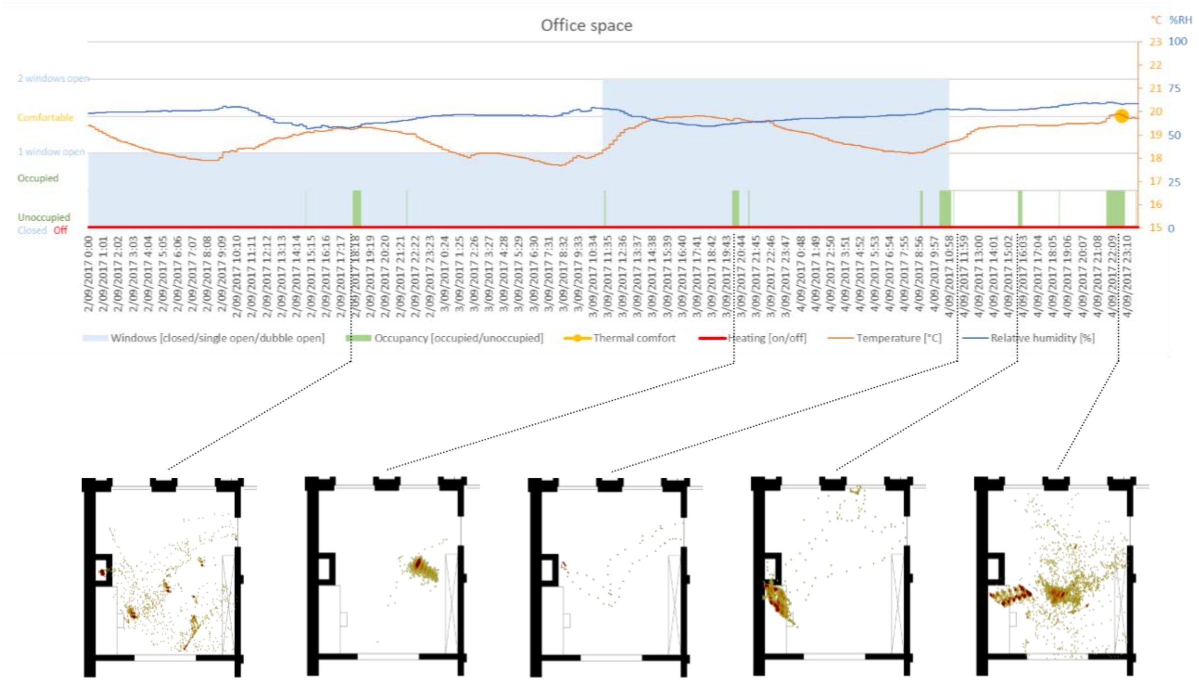

Figure 6: Timeline during 3 days from resident 2 in the office space of dwelling 2: combined data on occupation, actions, indoor climate, comfort experience and spatial use

5. Conclusion

In this paper, a mixed-method methodology to monitor occupant behaviour in relation to the indoor climate and energy consumption is presented. Five different methods are combined, i.e. an indoor localisation system, a smartphone survey, sticky notes, data loggers and documentation/interviews. Quantitative data on spatial use patterns, interactions with the buildings and systems and indoor and outdoor climate are obtained, as well as qualitative data on activity patterns and thermal comfort experience. Although the monitoring period is relatively intense for the residents, the data collection methods give good insights in the whole use of a dwelling. First results show that the methodology gives a fine-graded overview of the residents' spatial use within a room. By combining data of several methods discussed in this paper, further insights on spatial use in relation to energy consumption and thermal comfort experience can be obtained. These insights will be used to identify inefficiencies in spatial use and to optimize the energy efficiency.

6. References

ALARIFI, A., AL-SALMAN, A., ALSALEH, M., ALNAFESSAH, A., AL-HADHRAMI, S., AL-AMMAR, M. A. & AL-KHALIFA, H. S. 2016. Ultra Wideband Indoor Positioning Technologies: Analysis and Recent Advances. *Sensors,* 16**,** 36.

ANDERSEN. 2009. *Occupant behaviour with regard to control to the indoor environment.* PhD, Techical university of Denmark.

ANDERSON, K., SONG, K., LEE, S., LEE, H. & PARK, M. 2015. Energy consumption in households while unoccupied: Evidence from dormitories. *Energy and Buildings,* 87**,** 335-341.

CICH, G., KNAPEN, L., BELLEMANS, T., JANSSENS, D. & WETS, G. 2016. Threshold settings for TRIP/STOP detection in GPS traces. *Journal of Ambient Intelligence and Humanized Computing,* 7**,** 395-413.

EPBD 2002. Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings. .

EPBD 2010. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast).

EUROSTAT. 2016. *Average size of dwelling by household type and degree of urbanisation* [Online]. [Accessed].

GUERRA-SANTIN, O. & TWEED, C. A. 2015. In-use monitoring of buildings: An overview of data collection methods. *Energy and Buildings,* 93**,** 189-207.

GUERRA SANTIN, O., ITARD, L. & VISSCHER, H. 2009. The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock. *Energy and Buildings,* 41**,** 1223-1232.

KIM, J., DE DEAR, R., PARKINSON, T. & CANDIDO, C. 2017. Understanding patterns of adaptive comfort behaviour in the Sydney mixed-mode residential context. *Energy and Buildings,* 141**,** 274-283.

LABEODAN, T., ZEILER, W., BOXEM, G. & ZHAO, Y. 2015. Occupancy measurement in commercial office buildings for demand-driven control applications—A survey and detection system evaluation. *Energy and Buildings,* 93**,** 303-314.

MANU, S., SHUKLA, Y., RAWAL, R., THOMAS, L. E. & DE DEAR, R. 2016. Field studies of thermal comfort across multiple climate zones for the subcontinent: India Model for Adaptive Comfort (IMAC). *Building and Environment,* 98**,** 55-70.

MAUTZ, R. 2012. *IndoorPositioning Technologies.* ETH Zurich.

ONSETCOMP. 2017. *HOBO Temperature/Relative Humidity/Light/External Data Logger* [Online]. Available: http://www.onsetcomp.com/products/data-loggers/u12-012 [Accessed].

POZYX. 2017. *Pozyx Accurate positioning* [Online]. Available: https://www.pozyx.io/ [Accessed 19 december 2017].

RYU, S. H. & MOON, H. J. 2016. Development of an occupancy prediction model using indoor environmental data based on machine learning techniques. *Building and Environment,* 107**,** 1-9.

SANTIN, O. G. 2010. *Actual energy consumption in dwellings: The effect of energy performance regulations and occupant behaviour.* Doctor, University Delft.

VANDERSTRAETEN, L., VANNESTE, D. & RYCKEWAERT, M. 2016. Grote Woononderzoek 2013. Leuven.

WANG, Y., DE GROOT, R., BAKKER, F., WORTCHE, H. & LEEMANS, R. 2017. Thermal comfort in urban green spaces: a survey on a Dutch university campus. *Int J Biometeorol,* 61**,** 87-101.

WATSON, C. & THOMSON, K. 2005. Bringing post-occupancy evaluation to schools in scotland.

WONG, N. H. & SHAN, K. S. 2003. Thermal comfort in classrooms in the tropics. *Energy and buildings,* 35**,** 15.

YANG, J., SANTAMOURIS, M. & LEE, S. E. 2016. Review of occupancy sensing systems and occupancy modeling methodologies for the application in institutional buildings. *Energy and Buildings,* 121**,** 344-349.

ZOU, H., JIANG, H., YANG, J., XIE, L. & SPANOS, C. 2017. Non-intrusive occupancy sensing in commercial buildings. *Energy and Buildings,* 154**,** 633-643.