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Investigating human behaviour using sensors measuring the indoor climate and energy performance of three Dutch residential dwellings

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INVESTIGATING HUMAN BEHAVIOUR USING SENSORS MEASURING THE INDOOR CLIMATE AND ENERGY PERFORMANCE OF THREE DUTCH RESIDENTIAL DWELLINGS

Buildings don't use energy: People do. This leads to the following question [1]: Do highly efficient homes really save energy? According to recent studies, accurate building energy simulation for multiple buildings could not predict the actual energy consumption. This is called the 'energy performance gap'. The regulatory energy performance gap is found to deviate by +34% with an SD of 55% based on 62 case buildings in the United Kingdom (UK) [2]. In certain cases, the energy performance gap due to occupant behaviour was 300% [3]. In the Netherlands, it was shown that occupants of low-energy efficient buildings consumed less gas (for space heating and hot water) than expected, while the occupants of energy efficient buildings consumed more than expected [4]. This gap is attributed to factors such as climate, indoor design criteria, building energy & service systems, building envelope, building operation & maintenance and occupant behaviour [5]. Significant progress in investigating all the stated aspects has been made, except the latter - occupant behaviour.

This article summarises a master's thesis research at TU Delft that aimed to investigate if sensors can help improve occupant behaviour to reduce the energy consumption of typical Dutch residential dwellings. Furthermore, it seeks to answer questions like - Are micro-controllers and sensors a reliable mean of data collection? From three households, a variety of data was collected with the intention to study the impact of occupants using a novel and inexpensive (€14 per set-up) method of data collection. This called for bridging three fields - electronics, computer science and building physics.

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THEORY

Occupant behaviour prediction in buildings is complex, stochastic, multi-disciplinary and challenging. Typical human interventions such as heating/cooling, opening/closing windows, use of sunshades, hot water used, number of electrical appliances, lighting, and cooking (gas/electric) play an important role in predicting the actual energy usage. Over-simplification and negligence of these interventions during the design phase is responsible for the energy performance gap.

The energy consumption can be classified on the basis of hierarchy of needs - necessity (space heating, hot water, cooking, lighting and ventilation), convenience (washing machine, dryer and dishwasher) and luxury (entertainment unit, television and deep freezer).

Research suggested a need for inexpensive ways to collect data about occupant behaviour [5]. Commercially available data loggers were too expensive (around €700 per set-up) for the scope of this study, so a novel and inexpensive (€14 per set-up) method of data collection was defined.

The micro-controller ESP32 by Espressif systems best fitted the scope of this study. It has capabilities to receive the data from the sensors and transmit it wirelessly over the local Wi-Fi network. The relatively small size and economical price made it a good option for this study. The sensors were chosen specifically to measure parameters that were influenced by the occupants and affected the energy consumption of the house.

METHOD

From the three households a variety of data was collected with the intention to study the impact of occupants This included sensor data (temperature, relative humidity, occupancy, CO$_2$, window/door open/close, and specific appliances' energy consumption) and meter readings, which helped in studying and quantifying it. Documents, energy bills and the dwelling's EPC certificate helped study its past trends in terms of gas, electricity, and water use. Furthermore, they also helped in validating the data collected during the two-week observational period from 7th March - 21st March 2019 and reach conclusions.

Study candidates' houses

Case Study

The participants for this study were recruited through a demonstration based on the type of house, age of occupants, and consent. The demonstration was aimed at showcasing the sensor set-up to the audience and informing them how they can reduce or learn about their actions and save energy in their own houses. It was attended by 22 people and following the demonstration, an online form was circulated for the interested candidates. 13 out of the 22 people were interested in being a part of the study. The criteria for selecting the three candidates were:

- Information about the house and its characteristics - 4 out of 7 million houses in the Netherlands are terraced houses (*Rijtjeshuizen*). This ensured credible extrapolation of this study's results to other cases.
- Number of occupants and age group - The Netherlands has a large number of citizens around the age group of 26 and 49 years, which mainly comprises of families and couples. This is the reason two households around the 26 age group and one around the 49 age group were chosen.
- Co-operation and consent - Since this study involved installation of sensors within their house, their cooperation and consent were necessary.

After selecting the candidates, interviews were held with them before and after the observational period. This helped understand the usual patterns of energy use, typical occupancy and help answer unusual patterns found in the sensor data. The interviews helped confirm the observed sensor and energy data.

Senior couple

The senior couple's house is a 144 m^2 semi-detached terraced house constructed in 2016 and situated in the South Holland province. This household has two permanent occupants and 3 temporary members (children and grandchildren) who occasionally stay over during the week for a couple of days. This house uses natural gas for space heating and hot water. Electricity is used for cooking and household appliances. The ventilation strategy in this house is air supply through the window grilles and exhaust using an exhaust fan system with dedicated ducts in the toilet, kitchen and the bathroom. The main thermostat is situated in the living room/kitchen on the ground floor. It has a CO$_2$ sensor which helps the ventilator regulate the air quality and exhaust contaminants. The decentralised floor heating pipelines along with the temperature knobs (1-5 levels) offer personalised occupant thermal comfort in the rooms.

Young couple

The young couple's house is a 106 m^2 corner terraced house constructed in 2018 and located in the South Holland province. This house has two permanent residents. With the Dutch government introducing stricter regulations to make new houses nZEB (net zero energy building), this house sets a good example of it. High insulation levels, no gas connection, equipped with a modern HVAC system, heat pump and 31 PV panels on the roof emphasize the sustainability aspect. The main thermostat is present in the living room/kitchen. This offers temperature control and information about the heat pump usage like the monthly and yearly usage of the floor heating and hot tap water. Apart from that it also

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Table 1: About the chosen candidates and their house

Candidate	Senior Couple	Young Couple	Family
House type	Semi-detached row house	Corner row house	2 under 1 row house (Bovenwoning)
Year of construction	2016	2018	1934; renovated in 2000
Number of people living (P- permanent; T- temporary)	2-P 3-T	2-P 0-T	4-P 1-T
Total floor area (m²)	144	106	158
Ventilation	Natural supply and mechanical exhaust	Mechanical supply and exhaust	Natural supply and exhaust
Heating system	Floor heating with a gas boiler (CoP- 0.975)	Floor heating with electric heat pump (CoP- 2.40)	Radiators with gas based boiler (CoP- 0.94)
Cooling system	-	Night cooling	-
Hot water system	Gas circulation boiler (CoP- 0.95)	Electric heat pump (CoP- 1.90)	Gas circulation boiler (CoP- 0.94)
Cooking system	7400 W - Electric induction stove	7100 W - Electric induction stove	Gas stove
R-value (m²K/W) - Ground floor	5,00	5,00	0,09
R-value (m²K/W) - External walls	4,23	5,00	0,41-1,19
U-value (W/m²K) - Windows	1,20	0,70	~ 2,3
R-value (m²K/W) - Roof	5,17	6,00	1,19-2,5
Sources of energy	Electricity and Gas	Electricity and on-site PV (31)	Electricity and Gas
EPC	0,57	-0,02	~ 1,83

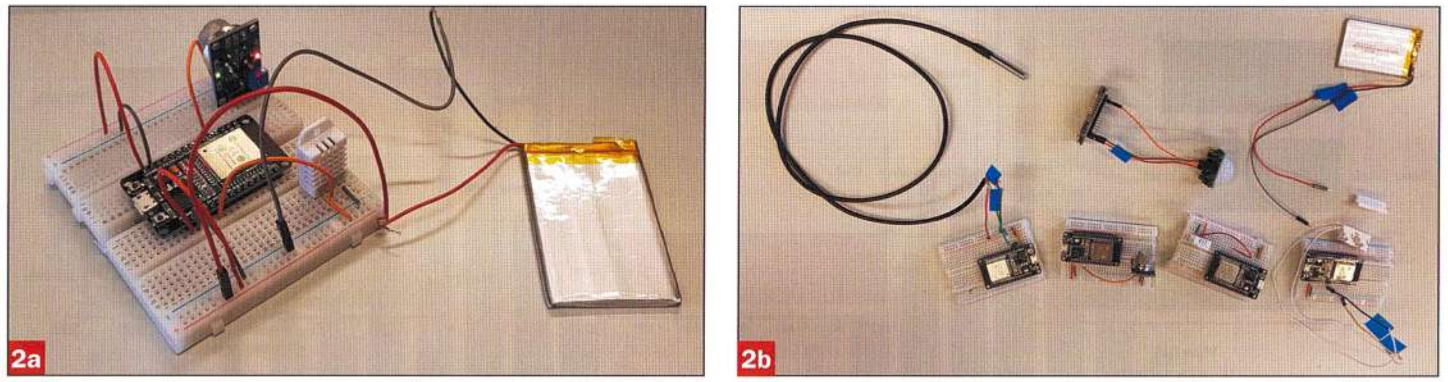
shows the hot water temperature and the space operative temperature. Similar to the senior couple's house, spaces have personalised floor heating knobs (1-5 levels) coupled with decentralised floor heating pipelines.

Family

The family house is a 158 m² 2/1 row house (*bovenwoning*), which was constructed in 1934 and renovated in 2000. This house is situated in Rotterdam - South Holland province. It accommodates 4 permanent members (2 - parents and 2 - children) and 1 temporary member (1 - child). In comparison to other houses, this house does not have a dedicated ventilation system and uses a conventional boiler (cv) with radiators for space heating, its temperature is regulated using a central thermostat in the living room. Furthermore, the house is surrounded by neighbouring houses on three sides - floor and both the adjacent sides. The indoor set-point temperature affects the heating demand and subsequently the neighbour effect influences it as well.

Table 2: Appliance plug meter readings during the observation period (7th - 21st March 2019)

House	Appliance	Runtime (DD:HH:MM)	Power (W) (Min and Max)	Energy (kWh)
Senior Couple	Coffee machine	00:09:54	0,9 & 2105	2,83
	Entertainment unit	02:03:05	0,5 & 14,7	0,64
	Washing machine and dryer	01:03:20	0,1 & 4378	16,71
	Ventilator (Exhaust only)	14:04:12	1,3 & 55,3	1,90
Young Couple	Television	04:01:42	0,1 & 179,6	6,33
	Fridge	05:16:55	0,3 & 233,7	5,47
	Washing machine	01:18:26	0,2 & 2401	5,69
	Ventilator (Heat Exchanger)	14:15:55	4,9 & 1717	5,89
Family	Electric hot water heater	00:09:45	0,1 & 2121	19,21
	Entertainment Unit	07:06:21	0,8 & 2039	6,52
	Washing machine	01:07:10	0,1 & 2155	9,77
	Dryer	00:08:42	0,1 & 2457	8,80



Different sensor set-ups for data collection

MICRO-CONTROLLER AND SENSOR SET-UP

The micro-controller ESP32 was connected to different sensors like the DHT22 - temperature and relative humidity, MQ135 - CO_2 levels (figure 2 (a)), DS18B20 - surface temperature, HC-SR501 - occupancy sensor and Reed Switch - state of windows/doors (figure 2(b)). These sensors were selected because of the high accuracy, low noise levels and relatively low cost. These sensors along with other ways (schedule and meters) were used to collect data. In order to remotely collect data from the sensors, the micro-controllers were programmed to deep-sleep for 30 minutes (to save battery energy), wake up, send the data to the cloud over Wi-Fi and deep sleep again. The data was sent using an IFTTT server.

Unique files and servers were created for all the sensor nodes, this avoided dependency on a specific micro-controller. Since the data was being collected real-time and stored in the cloud, it meant it could be accessed and viewed remotely by the researcher. Thus, allowing timely checks for errors and sensor malfunction. The micro-controller ESP32 and a 4500 mAh battery were placed in a fire-proof bag (figure 3 (a),(b) & (d)). For accurate and correct readings, the sensors were placed outside the

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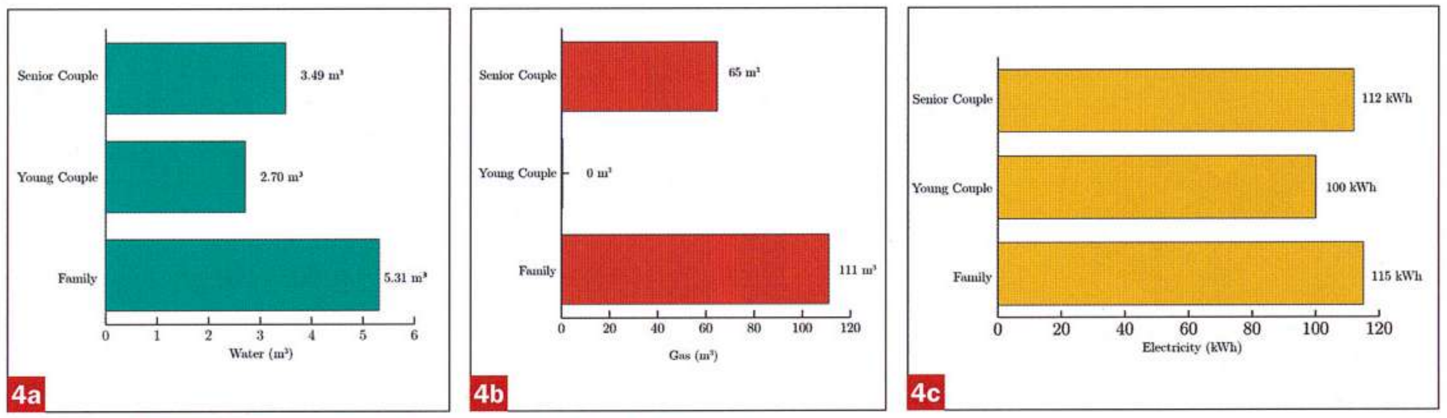
Installed sensors at the study candidates' houses



Water, gas and electricity usage during the observation period (7th-21st March 2019)

bag. This set-up made the sensor placement flexible since it did not depend on a AC wall outlet. Furthermore, it allowed the sensors to collect readings at the appropriate location in space without constraints and therefore being representative of the entire space.

In addition to sensors, energy plug meters were installed on appliances to monitor their usage during the observational period. The appliances that were monitored were decided by their usage period, frequency, and power.

In the three houses, the water meters were conventional and did not distinguish between the usage timings in the three houses. Gas meters were conventional and did not differentiate between the peak and non-peak hours in the three houses. The senior couple and the family households utilised gas and the young couple's house did not. In the senior couple's house, gas was used for floor heating and hot tap water. Unlike the family house, gas is not used for cooking. In the family, gas was used for space heating, hot water, and cooking. Electricity usage in the three houses was measured using smart meters. These meters showed peak and off-peak readings for electricity consumption and production (PV on-site). The peak hours included 07:00-23:00 on weekdays and the off-peak hours included 23:00-07:00 on weekdays and weekends. The three houses used electricity for different purposes. In the senior couple's house, it was used for household-related purposes except for the exhaust fan system and circulation pump. In the young couple's house it was used for both household (50%) as well as building-related (50%) purposes. Building-related purposes included mechanical ventilation supply and exhaust, heating, and cooling. In addition to the 31 PV panels on the roof, the house is connected to the grid. This allowed for the excess on-site energy to be sent to the grid and vice-versa during winters. In the family house electricity was used for only household purposes.

SIMULATIONS

In addition to support the conclusions from the observational period, historical data of the houses was obtained. The past energy usage (gas and electricity) of the senior couple and family's house gave an informative perspective on how occupant behaviour affected the energy consumption of the two houses. Historical energy data prior to November 2018 was not available in the young couple's case since the house was recently constructed. So, a validated dynamic energy model in IES(VE) 2018 was used to simulate their yearly energy usage and further learn about their usage pattern.

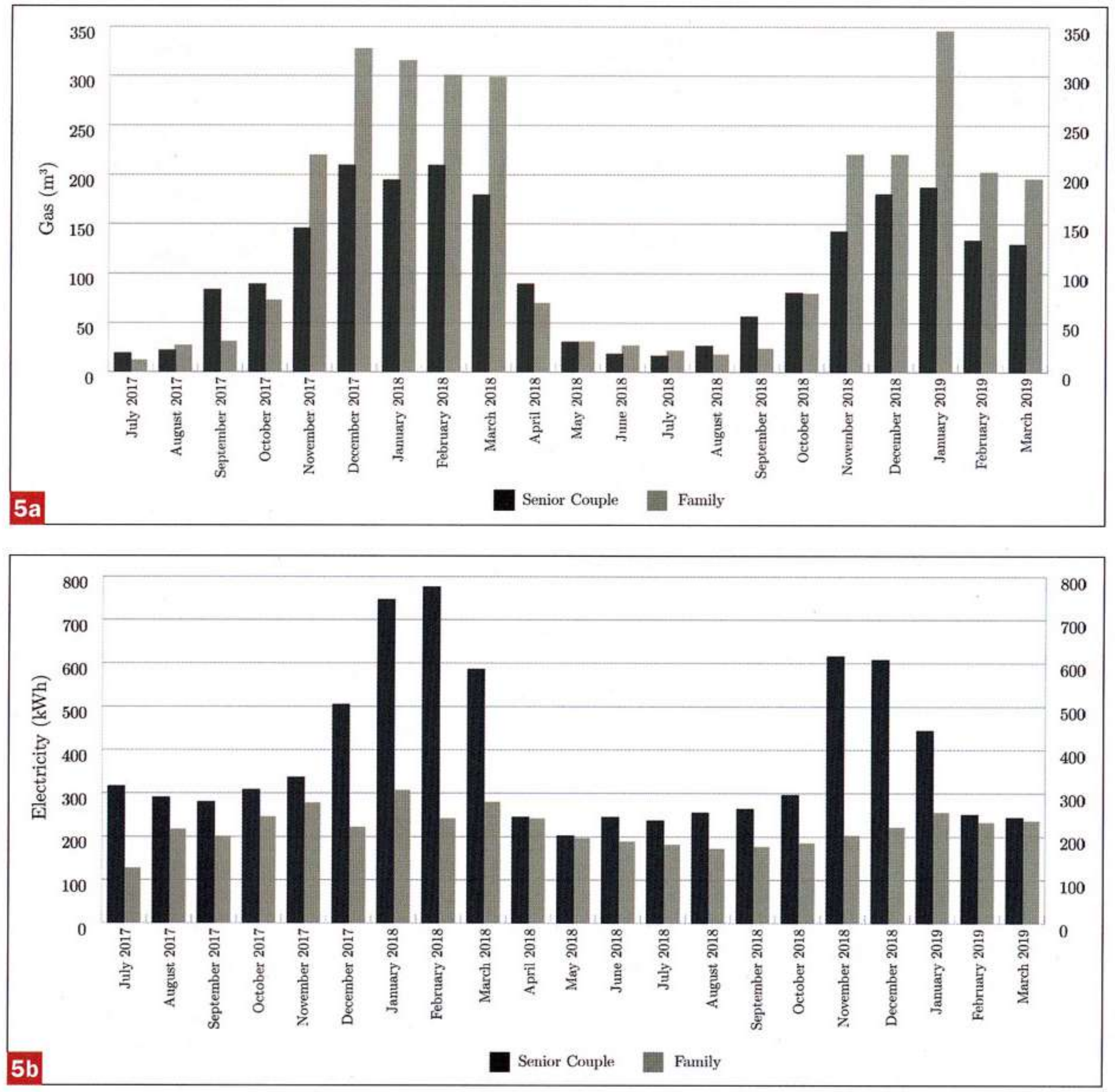
RESULTS

Measurement period

The water usage (figure 4 (a)) in three houses is relatively easy to predict as it has a direct correlation with the number of occupants (permanent and temporary) in the house. The senior couple (2 permanent occupants and 3 temporary occupants) have children and guests occasionally over the week and consumed 3.49 m^3 of water (during the observational period - March 7th - 21st). This is higher than the young couple's house which consumed 2.70 m^3 during observational period with 2 permanent occupants and 0 temporary occupants. Lastly, the family house has the highest consumption of water with 5.31 m^3 (during observational period), which is evident because of its 4 permanent and 1 temporary occupants.

The gas usage is the highest in the family house because of heating (space and water). Cooking also contributes to this number but it is not significant enough when compared to the heating. The senior couple's house used 65 m^3 during the two-week observation period. The external temperature during this period was on average between 8-10°C, which is close to the yearly average outside temperature of the Netherlands.

The installed sensor data revealed information about the users' indoor preferences such as the average indoor operative temperature (T) and relative humidity (RH) levels in the three houses. The location of the sensors in the house was based on the floor area and usage frequency, so that it could be representative of the entire house and allowed for drawing reliable conclusions. In the living room of the three houses, the averaged values over the observational period were - senior couple - T - 21°C, RH - 48%, young couple - 18°C, RH 46% and family - T - 20°C, RH - 48%. The temperature fluctuations were the highest (±4.5°C) in the family house (living room and master bedroom) because of the low insulation levels and frequent opening of windows for ventilation. The master bedroom saw deeper drops in temperature because the windows were left open for ventilation throughout the night. The temperature fluctuations were low in the young couple's house because of the high levels of insulation, mechanical supply and exhaust of air (so the windows remained closed for most of the period). The relative humidity levels were usually between 40-60% and the distribution across the time period was unsystematic except in the young couple's house. In their house, it followed a pattern because of the mechanical ventilation (supply and exhaust), as opposed to the other two houses, where it depended on various other factors such as the ventilation strategy, occupant presence, kitchen schedule and windows. In the master bedroom, the averaged values over the observational period were - senior couple - T - 20°C, RH - 46%, young couple - T - 18°C, RH - 50% and family - T - 17.5°C and no RH recorded due to sensor malfunction. The CO_2 sensor malfunctioned due to varying voltage supplied by the lipo battery and since these sensors rely on voltage changes to show the CO_2 levels, the calibrated sensors were rendered uncredible for this study. So, an assumption was made that the previously installed CO_2 sensors (HVAC system) functioned properly maintained the levels between 400-1200 ppm, thereby conforming to the regulations inside the houses.



Past energy consumption (energy bills) of the senior and the family houses

The interviews with candidates revealed their occupancy schedules. The reason this was important was because often over-simplifications in occupancy schedules while modelling leads to inaccurate predictions. In the senior couple's household, the husband had a normal 9-5 working schedule, the wife's working schedule varied due to her health care profession. The young couple's house was the usual 9-5 working day schedule. In the family house, at least one occupant was present in the house during most of the week and in the weekends the house would be empty. This information helped in setting schedules for the dynamic performance modelling.

Yearly data

The monthly variation in the gas usage of the senior and family house is predominantly due to the different insulation levels (walls, ground, windows and roof), floor area, and the CoP (see table 1) of the heating system and occupant behaviour (windows/grilles) of the two households. It can be seen that during the warm months of the year, the gas usage between the two households is almost same. This is because during these months, the gas used for space heating is negligible. The hot water

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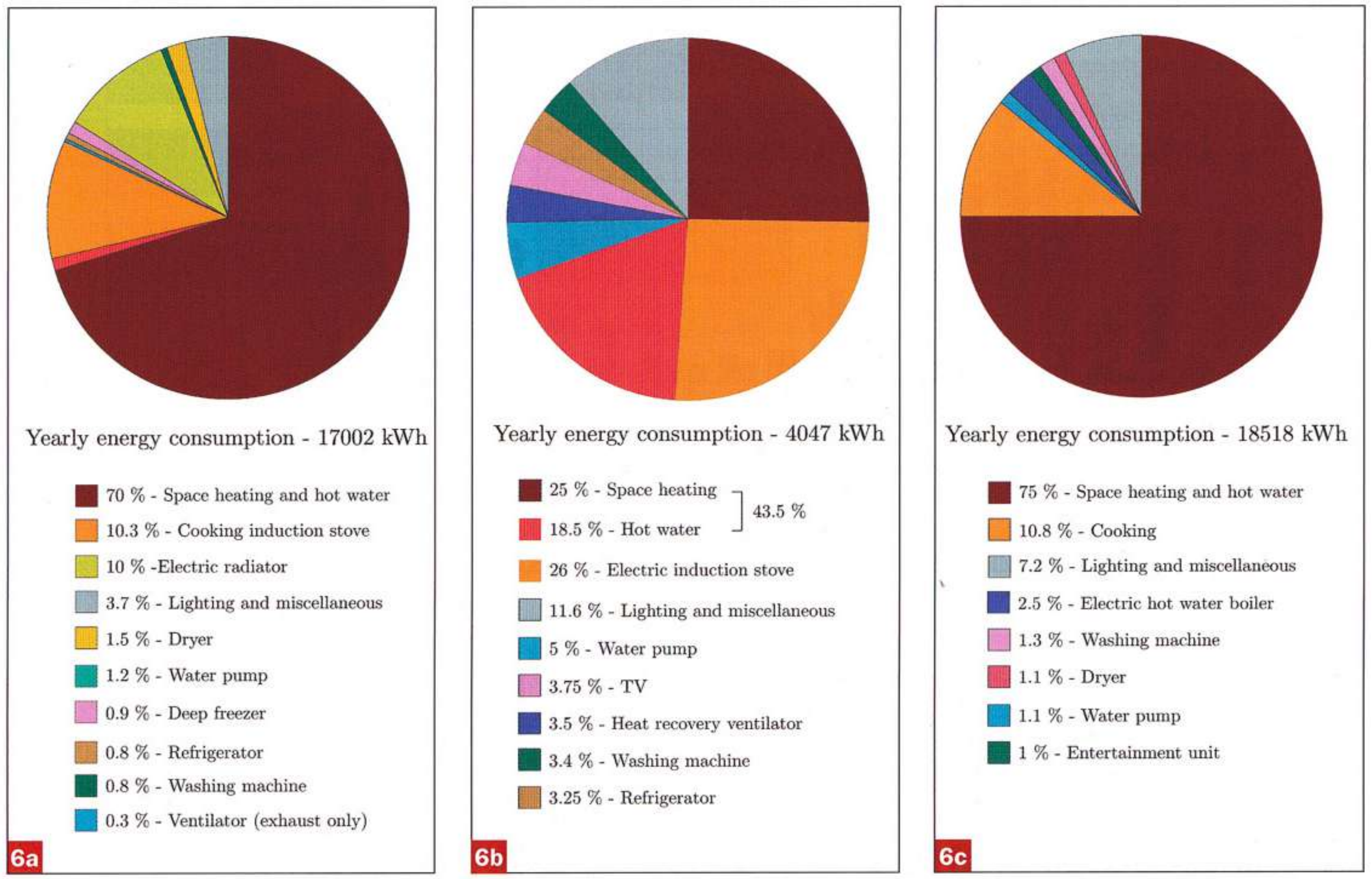


Annual energy usage breakdown

usage is also low when compared to other months due to the high outdoor temperature.

The influence of occupant behaviour is clearly visible from the senior couple's past electricity consumption. Generally, the electricity consumption unlike the gas consumption is mostly stable throughout the year because usually external temperature is not a driving factor for the electricity consumption (mostly household appliances). But in the senior couple's house the higher peaks in the colder months are due to the use of a 2000 W electric radiator in the non-insulated garage. This garage was used to store food items and the radiator prevented it from freezing during the winter.

It was observed that the necessary energy use was dominant when compared to convenience and luxury energy usage. Space heating energy demand was seen to be higher in houses with higher floor area (see table 1 and figure 6). Furthermore, the deviation between the EPC and space heating energy was dependent on the occupant behaviour in newly built houses (senior couple and young couple). In the young couple's house, the windows were rarely opened (maybe once or twice in a month) and this was because the contractor had advised them not to. Moreover, the set-point temperature in the house was on an average 18°C - lower than what the EPC assumed in their case. Which explains the lower actual energy consumption when compared to its prediction during the design phase (obtained from EPC certificate). In the senior couple's house, the window grilles could be considered as an 'open leak' for the outside cold air to enter. This along with a higher set-point temperature and frequent opening of the windows in the kitchen and the master bedroom explain the higher energy consumption even at high levels of insulation.

From the dynamic simulation, sensor data, interviews, and energy bills of the occupants, it was concluded that the energy consumption for lighting is over-estimated by up to 60% in EPC. This is due to two reasons 1. Use of highly efficient and lesser quantity of light bulbs (LEDs) and 2. The actual working hours are less due to occupant behaviour. We see that the actual yearly energy consumption depends greatly on the floor surface area of the house. The EPC prediction is accurate (+0.60%) in the family house's case, which is an old house constructed in 1934 and renovated in 2000. This is because, after a certain limit of insulation level, the effect of occupant behaviour in poorly insulated houses stagnates (like in the family house) and is therefore negligible when compared to the total energy consumption. For instance, the space heating demand in a poorly insulated house shows little deviation due to the windows opened by its occupants. Whereas, in newly built houses when you compare the EPC with its actual usage, they are off by +39 % in the senior couple's house and by -45 % in the young couple's house. This therefore shows that occupant behaviour plays a much more significant role in newly built houses (senior and young couples' house) than in old ones (family house).

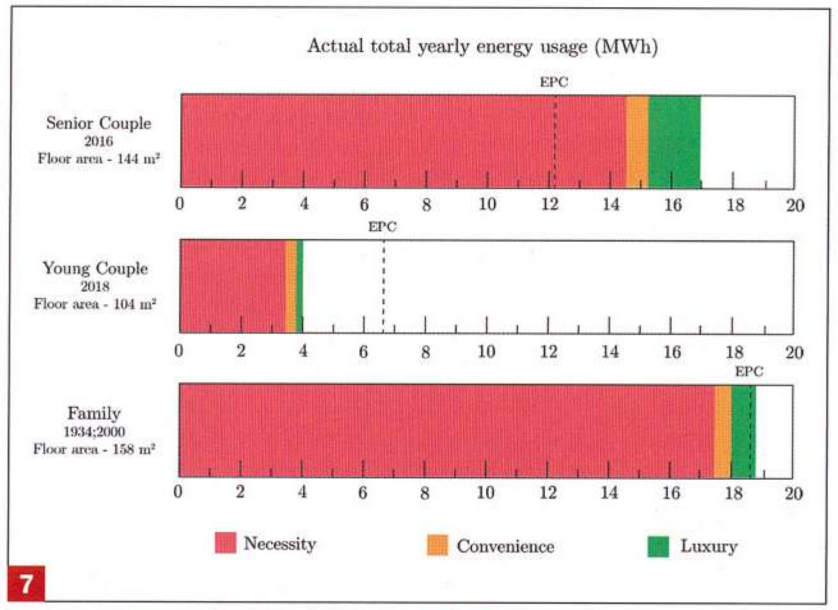
During the observational period (7th-21st March 2019) the energy costs that the senior couple, young couple and the family houses paid were € 82, € 30, and € 123 respectively and annually, they were € 2289, € 1100, and € 2031 respectively. In the young couple's case, since they have 31 PV panels, they earn € 395 at the end of the year. It is seen that the senior couple's household paid € 258 more than the family house. This was predominantly due to the usage of the 2000 W electric radiator in the non-insulated garage. If the electric radiator in the garage would not have been used, then the senior couple would have saved approximately € 420.

Ventilation - In the senior couple's house, the manual window grilles were present in the entire house. More often than not these grilles were left open for ventilation, thereby serving as a potential leak for the loss of space heating energy. Moreover, since these are window grilles, their air tightness in closed position is limited. Also, visually it is difficult to see if they are closed or open. This explains the increased energy use in their house despite the presence of higher levels of insulation and a relatively energy-efficient HVAC system. This peak was the result of occupant behaviour. It was partly intentional and partly unintentional due to forgetfulness of the occupants. A possible way to solve this would be to install CO_2 controlled window grilles, which regulate the opening of these grilles according to the CO_2 levels inside.

Furthermore, in the young couple's house the HVAC system consumes 50% of the entire house's energy consumption. In this situation, a possible solution could be to equip the house with sensors and actuators. A small window experiment was done at the young couple's house to estimate the energy loss that occurred when they were opened. During this experiment it was observed that a great volume of air (217 m^3/hour) entered the house when the windows were opened for one hour. This value is well above the stipulated level (25 m^3/hour.person) set by the Dutch building decree.

Permanent and temporary occupants - In the senior couple and family houses, there was an influence of temporary occupants. This can be seen from the water consumption - hot water in particular. Data regarding this aspect would help in making an informed design for future buildings that have strict energy goals.

Space heating and hot water consumption - From the annual gas usage (m^3), heat pump usage data (kWh) and the energy breakdown of the three houses (kWh) we can see that the energy used for space heating and hot water is significantly high (Senior couple - 70%, Young couple - 43.5% and Family - 75% of the total yearly energy usage). In the young couple's house, space heating and hot water used - 25% and 18.5% respectively. The space heating demand is low when compared to the other houses (senior couple - 70% and family - 75%) due to the heat pump (CoP - 2.15 and other two houses - 0.95), higher levels of insulation, lower floor area and occupant intervention such as lower set-point temperature. In order to reduce this demand, implementation of possible measures such as highly efficient heat pumps, aquifer thermal energy storage and shower drain heat exchanger individually or in combination could result in high energy savings.



Comparison of the actual yearly energy usage with EPC

CONCLUSIONS

Occupant behaviour plays a significant role in influencing the energy consumption of a house. This influence was quantified in the three houses and was found to be +39% (Senior couple), -45% (Young couple) and +0.60% (Family) when compared to a standard user assumed during the energy prediction of the EPC. Furthermore, the findings and conclusions of this research were as follows.

Lighting - Energy used for lighting is over-estimated in the houses. This estimation was found to be off by -60% in the young couple's house when compared to the EPC prediction during the design phase, with the EPC being conservative. Since this a high difference necessary steps to accurately account for lighting need to be taken while issuing the EPC certificate.

Theoretical vs Actual CoP of the heat pump - The heat pump CoP in the young couple's house was expected to be 2.55 but during the observation period it was observed to be 2.15 (1.90 - hot tap water and 2.40 - space heating). Since the CoP varies throughout the year due to external temperature changes, this observation was made when the external temperature was the yearly average - 8-11°C, thereby providing a valid and credible estimation. Further investigation into the actual working CoP and its deterioration over time (years) is required for accurate predictions.

Accuracy and unpredictability of EPC energy certificates - The EPC statically estimates the energy consumption of houses by assuming standard occupant behaviour. In the older houses, the poor insulation levels already peak the total energy consumption to such an extent that in terms of energy it is difficult to observe or quantify the effect of an open window. Therefore in older

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houses the quantified effect (in percentage) of occupant behaviour of the total energy usage is relatively low, thereby making it logically to first solve the non-occupant related factors like insulation levels, HVAC system and then tackle occupant behaviour and its effects. As a result of that it predicts accurately (+0.60%) the energy consumption of old houses (family house) where the influence of occupant's interventions are less evident. Whereas on the other hand, newly built houses with higher insulation and optimisation levels are prone to greater fluctuations due to occupant behaviour and their actions such as opening the windows amongst others. This is seen in the senior couple's (+39%) and the young couple's (-45%) households which were constructed in 2016 and 2018 respectively.

Data visualisation and presentation - Visualisation and presentation of data is pivotal. This can be seen in the senior couple's case where the electric radiator in the poorly insulated garage more than doubled their monthly electricity consumption during the colder months. If this data was presented as a bar graph every month against the entire year's data to the occupants, then this could have been prevented. Furthermore, if individual appliances monitor and display their energy consumption it could lead to an increased awareness and valuable insights to the usage behaviour. This would further lead to a higher familiarity with unit of energy used and its corresponding monetary value. As a result, this could help the occupants make informed choices, therefore leading to possible energy savings.

Ventilation - Often the occupants' negligence and mistakes cost energy. For instance, in the senior couple's house the window grilles were open even when the occupants were absent or when CO_2 levels were well below the required level. Furthermore, in the young couple's house the HVAC system consumes 50% of the entire house's energy consumption. In this situation, a possible solution could be to equip the house with sensors and actuators.

Sensors and actuators in place of HVAC systems? - With the rapidly advancing technology, the concept of building physics with the knowledge of internet of things can be explored and implemented in buildings, therefore making them much smarter and more efficient. Newer technologies often face resistance from people especially when we consider their homes. One way to tackle it would be by allowing the users to customise it and then putting it in perspective with previous usage patterns. Highly insulated homes could save energy but at the cost of inferior indoor conditions. Sensors and actuators (windows, sunshades, lighting, heating and cooling) with a 2 way interaction could respond to external conditions (high temperature, rain and others) without the occupants' help to achieve either comfort, lower energy consumption or both depending on the case.

Highly insulated homes: the solution? - Simulations revealed the indoor temperatures in the three households during the entire year. From the dynamic energy simulations, it was found that due to the high levels of insulation and triple glazing in the young couple's house, the temperatures could go up to 33°C in the living room whereas in the senior couple's house it would reach 27.5°C and in the family's house 29°C.

How to use your home? - Since this study investigated and found that occupant behaviour does play an important role in buildings and can eventually cause an imbalance between the commonly accounted energy driving factors (climate, indoor design criteria, building energy service systems, building envelope, building operation & maintenance) and occupant behaviour, it is important to address it and ensure that it does not cause any significant deviations in the actual energy consumption. One possible way to approach this would be to provide a manual -" How to use your home?" to the occupants. Which would inform them about the energy implications of their choices. This will ensure that the occupants are aware of the choices they make. Government regulations to make this a legal obligation could help introduce this concept into buildings. ■

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VAN GAS LOS (DEEL 3)

In mijn vorige columns schreef ik over mijn zoektocht naar een vervanger van mijn oude gasketel. Stap voor stap onderzoek ik wat de mogelijkheden zijn om mijn huis uit 1913 van het gas af te halen. Maar soms komen zaken onverwachts in een stroomversnelling. Op een maandagmorgen stond ik me onder mijn douche te ergeren dat het zo lang duurde voor het water warm werd. En kwam toen tot de conclusie dat het water überhaupt niet warm werd. De CV-ketel was in storing. Resetten mocht niet baten, en ik moest het doen met een koude douche die ochtend. De monteur kon gelukkig snel langskomen, maar concludeerde ook dat de printplaat stuk was, en dat een nieuwe erg prijzig was. En eigenlijk niet de moeite waard voor een ketel uit 2003. Ik werd dus voor het blok gezet: ben ik al klaar om van het gas af te gaan? Wachten op de aanleg van een warmtenet was nu zeker geen optie meer. Een pelletkachel vond ik ook wat controversieel gezien de recente vraagtekens die bij de duurzaamheid van biomassa worden gezet. Een warmtepomp leek het meest geschikt. En omdat ik in een appartement woon en ik niet dacht dat mijn buren akkoord zouden gaan met een bron in de gemeenschappelijke tuin, besloot ik voor een lucht-water warmtepomp te gaan.

Mijn grootste zorg was het geluid van de buitenunit, omdat deze op mijn dakterras naast het slaapkamerraam van de buren zou komen te staan. Vanaf 1 april dit jaar gelden er bovendien ook Bouwbesluit-eisen voor het geluid van buitenunits voor nieuwbouwwoningen: maximaal 40 dB(A) op de perceelsgrens. Ik vond een stille buitenunit, en ook nog een speciale geluiddempende omkasting die het geluiddrukniveau op 1 meter afstand tot 37 dB(A) terug zou brengen. Dat vond ik best acceptabel want, zo redeneerde ik: 's avonds als de buren slapen, slaap ik ook en staat hij toch niet aan. In de zomer als ze buiten zitten hoeft hij alleen maar een beetje warm water te maken.

Een andere zorg was de warmtapwatercapaciteit. Eén van mijn grootste milieuzondes is mijn regendouche. Hij verbruikt 12 liter water per minuut (wat voor een regendouche overigens nog best meevalt), ik douche heet en ik sta er graag lang onder. En dan moet er ook nog warm water over zijn voor mijn vriend. Maar ook dit leek geen belemmering te zijn (mits hij maximaal 10 minuten doucht).

Het enige wat ik nu nog moest doen was de buren mee krijgen. Want hoewel ik met de geluidwerende omkasting zou voldoen aan alle aankomende wet- en regelgeving omtrent geluid van de installatie, betekent het voldoen aan de wet niet dat je geen overlast kunt veroorzaken. Mijn buren waren allerminst te spreken over het idee van een buitenunit, hoe stil ook. De weerstand was enorm. Mijn betoog dat er een geluidwerende omkasting omheen zou komen en het achtergrondgeluid in Den Haag het resterende geluid van die buitenunit wel zou maskeren haalde niets uit. Het vooroordeel was te sterk. Eén rondje googelen en je vindt immers een waslijst met horrorverhalen. De goede voorbeelden waarbij buitenunits correct en vakkundig zijn geplaatst in overleg met een akoestisch adviseur zijn duidelijk minder populair in de zoeklijsten. Wat jammer is want zo staat deze optie om gasloos te gaan direct al 1-0 achter.

Ik hecht waarde aan een goede band met mijn buren. En ik weet ook dat als het om geluid gaat geldt: als je het denkt te kunnen horen, dan hoor je het. Een vooroordeel kan daardoor onderdeel zijn van de ervaring van overlast. Uit het veld geslagen kroop ik terug achter mijn laptop, op zoek naar nieuwe mogelijkheden. De les die ik hieruit heb geleerd: betrek je buren al ver van tevoren bij je ambitie om van het gas af te gaan. Ga eventueel met ze bij een paar referentieprojecten kijken. Zodat als jij klaar bent om van het gas af te gaan, zij dat ook zijn. ■

Annebeth Muntinga

Annebeth Muntinga:
"Ik ben een bouwfysicus die gelooft dat onze toekomst duurzaam is. En ik ben dankbaar dat ik hier als ingenieur een bijdrage aan kan leveren."