Smart Building Energy and Comfort Management Based on Sensor Activity Recognition and Prediction

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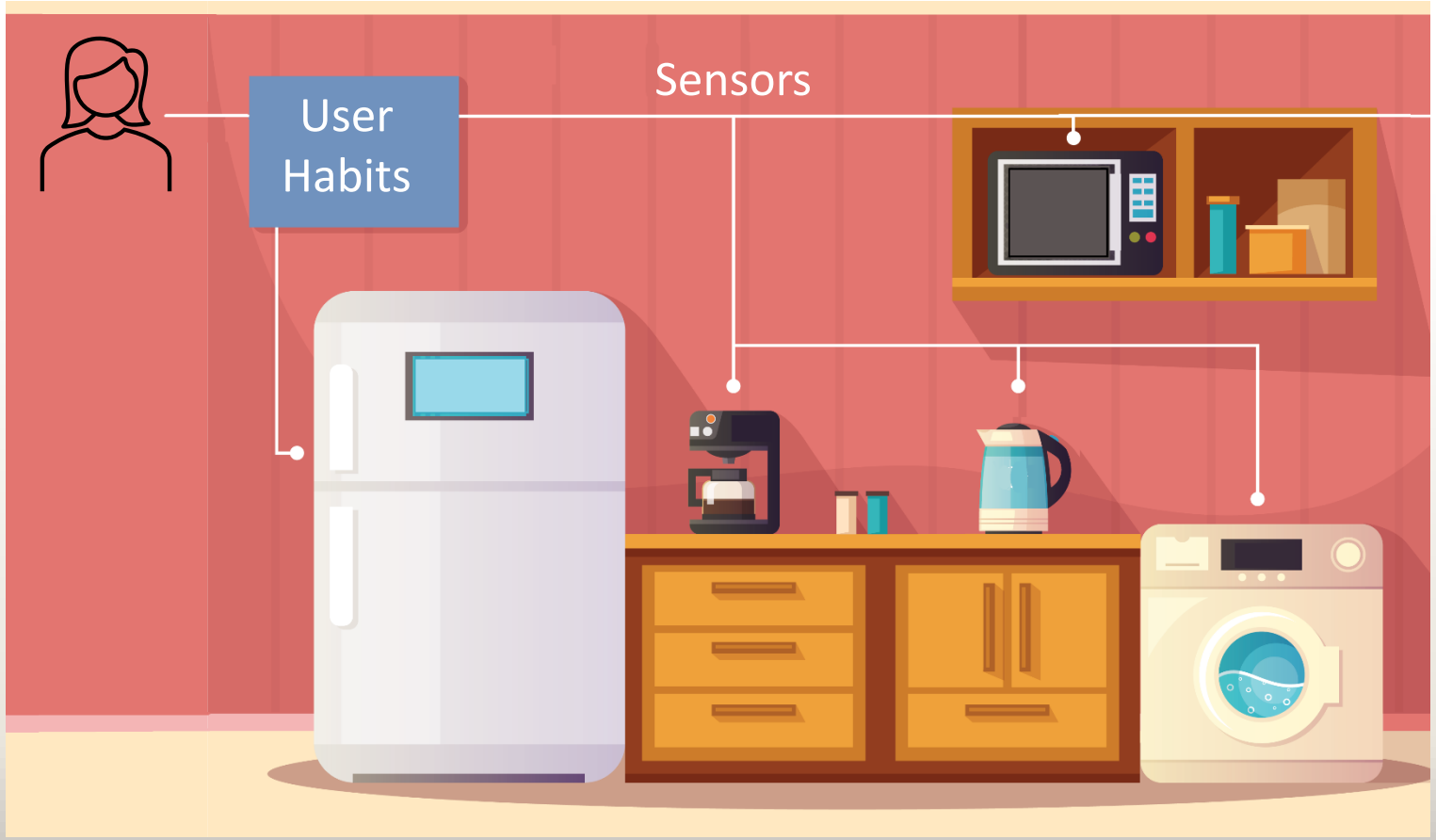
Introduction

- **Building Energy and Comfort Management (BECM) System** -> providing support to users of various intelligent buildings
  - Monitoring the environment and its users
  - Understand users' behaviours, preferences and habits
  - Efficient management of energy consumption
- **Support cost-effective solutions to appliance management**
- **Monitor users' habits ->** learning their preferences and predicting their sequences of performed activities and appliance usage during the day

- Most of the literature considers user comfort as a set of hard constraints on appliance usage, which are a priori set based on general statistics
- Some research has focused on Human Activity Recognition and Prediction, without considering a complex system for Smart Building solutions

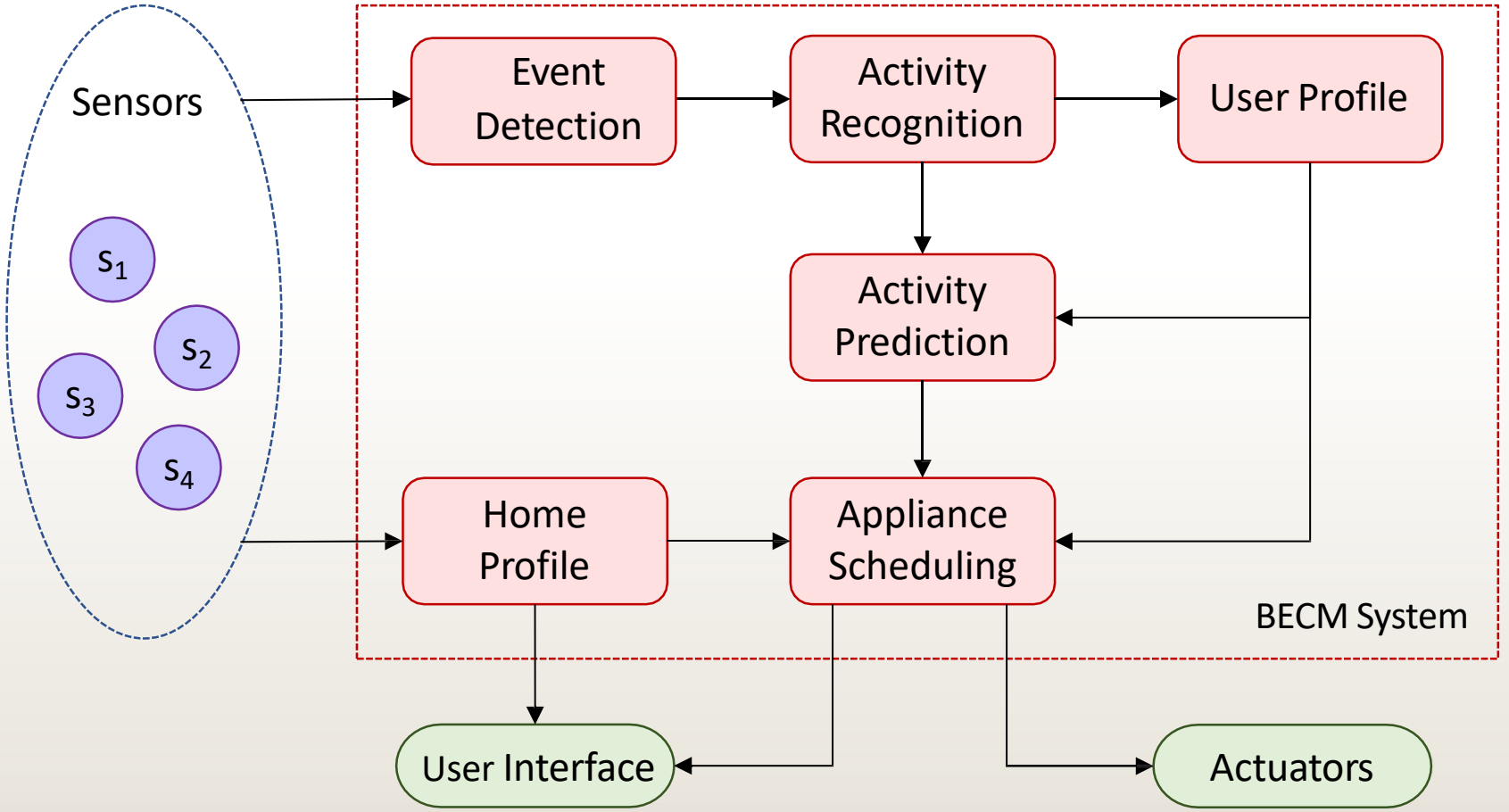
Scenario and Objective

- Automatically and unobtrusively monitoring of user habits about appliance usage



- Usage of sensor networks distributed throughout an intelligent building
- Recognition of the activities usually performed by users
- Prediction of future activities, especially activities that imply appliance usage
- Energy-cost-saving appliance scheduling, according to user behaviour and user annoyance

Overview of the proposed system



Activity Recognition Module

- **Training Phase**
  - Each activity instance is observed within an observation time window O_A, registering the events detected by the sensors
  - For example: space of events $\boldsymbol{e} = [e_1, e_2, e_3]$, instances of activities $\boldsymbol{A_1}, \boldsymbol{A_2}$

$$\boldsymbol{A_1} \left\{ \begin{array}{l} \boldsymbol{I_{11}} = [e_1, e_2, e_3, \ldots] \\ \boldsymbol{I_{12}} = [e_2, e_1, e_3, \ldots] \end{array} \right. \qquad \boldsymbol{F_{11}} = [0.55, 0.33, 0.22]$$

$$\boldsymbol{A_2} \rightarrow \boldsymbol{I_{11}} = [e_3, e_2, e_3, \ldots] \qquad \boldsymbol{F_{12}} = [0.34, 0.05, 0.79]$$

$$\boldsymbol{F_{21}} = [0.51, 0.35, 0.18]$$

rates of detected event occurrences

  - Model Vector for each activity

$$\boldsymbol{m_1} = mean_k(\boldsymbol{F_{1k}}) = [0.53, 0.34, 0.20]$$

$$\boldsymbol{m_2} = mean_k(\boldsymbol{F_{1k}}) = [0.34, 0.05, 0.79]$$

average rate for all the observed instances of the same activity

Activity Recognition Module

- **Running Phase**
  - Sequences of detected events are divided into subsequences using an observation window $O^W(t)$ starting at time ***t***

$$O^w = [e_1, e_2, e_1, e_2, e_3, e_1]$$

  - The window contains a certain number of events equal to its size W
  - Feature Vector of subsequences computed as the vectors in the **Training Phase**

$$\boldsymbol{F_1^W} = [0.50, 0.33, 0.17]$$

  - The sequences of detected events are classified based on their probability to belong to a given activity

Activity Prediction Module

- Provides a possible scenario in time $\boldsymbol{t}$ ahead in the future
- Probabilities of every activity $\boldsymbol{A_j}$ in $\boldsymbol{t}$ are calculated thanks to statistics information about all the activities $\boldsymbol{A_i}$ previously performed
- The probability for each activity is translated in the probability of one of the appliance in the house to be used at time $\boldsymbol{t}$
- The output obtained is used by the next **Appliance Scheduling Module** to make a coherent scheduling of the appliances and the evaluations on energy consumption

Appliance Scheduling Module

- **Appliance Scheduling Algorithm** -> dynamically shifts tasks of controlled appliances to times when it is more convenient
- The scheduling of appliances is evaluated according to their related cost, calculated based on energy consumption and user annoyance

ACTIVITY	APPLIANCE
Housekeeping	Vacuum Cleaner
Meal Preparation	Microwave Oven
Relax	TV
Wash Dishes	Water Heater
Work	Laptop/Pc
Taking Shower	Water Heater
Laundry	Washing Machine
Wash Dishes with Dish Washer	Dish Washer

Appliances and activities in red are the ones controlled for the scheduling

The algorithm performs the scheduling of the appliances corresponding to activities that have value of probability higher than a certain threshold

Simulations and Results

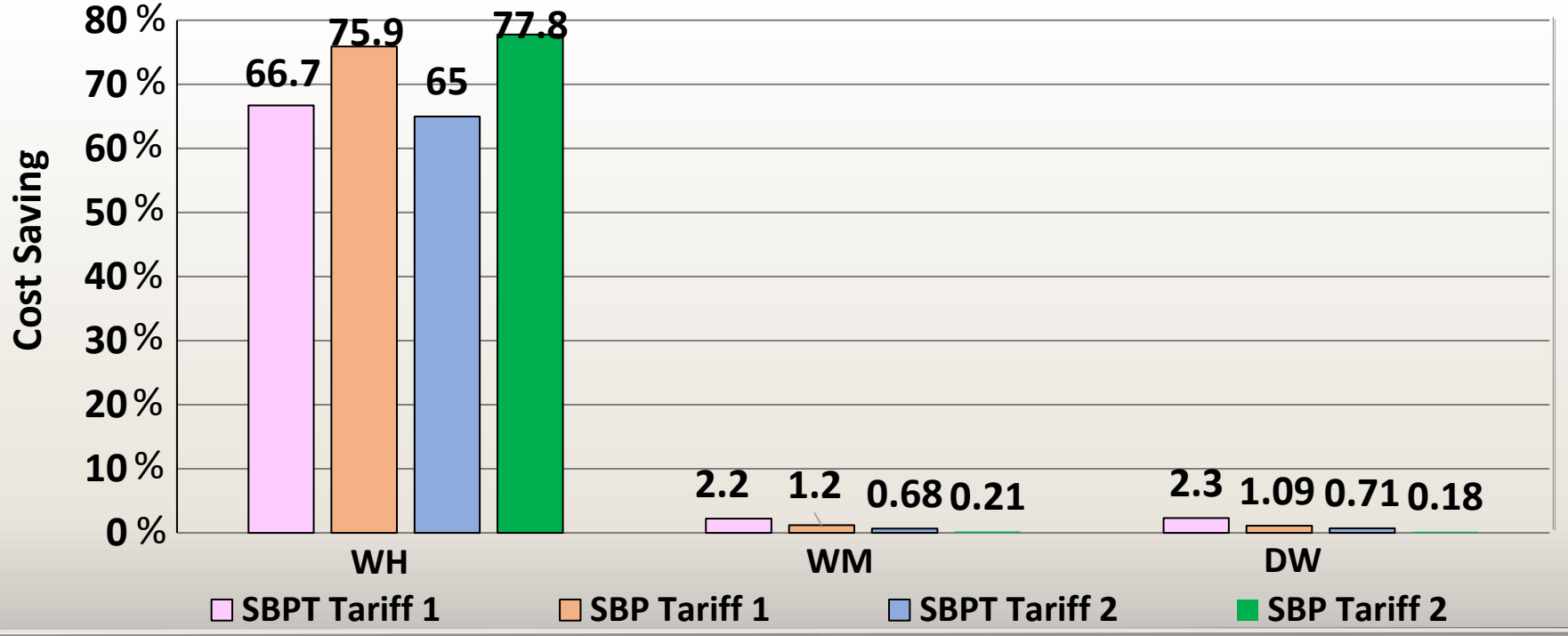
- **Activity Recognition Algorithm ->** Accuracy of 82.3%
- **Activity Prediction Algorithm ->** Accuracy of 67%
- **Scheduling Algorithm ->** Three different scenarios:
  - Without Scheduling Algorithm – WSA
  - Sheduling Based on Perfect Time – SBPT
  - Scheduling Based on Probability – SBP

Weekends,holidays and everyday (19:00-8:00)	Everyday (8:00-19:00)
Tariff 1 0.0534 €/kWh	Tariff 1 0.07666 €/kWh
Tariff 1 0.06799 €/kWh	Tariff 1 0.07666 €/kWh

	WSA	SBPT	SBP
Energy consumption in kWh/week	65.43	42.43	35.83
Cost Saving with Tariff 1	-	50.4%	64.7%
Cost Saving with Tariff 2	-	49.2%	63.2%

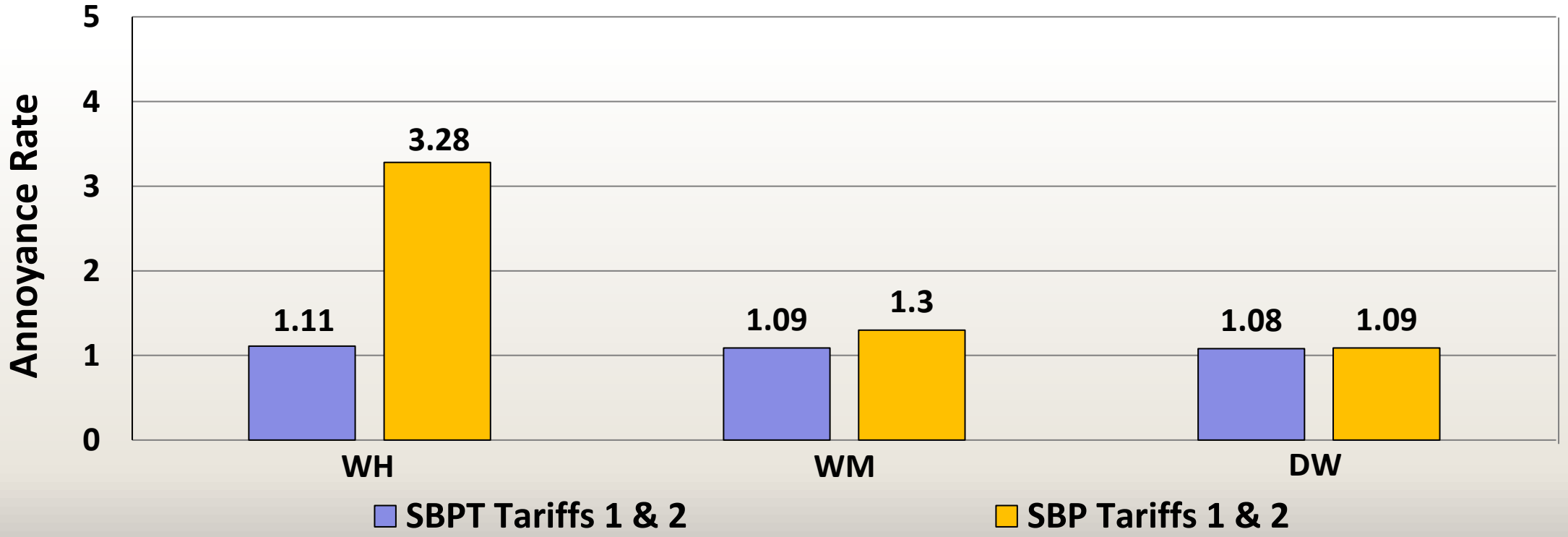
Simulations and Results

- Most of the savings come especially from a wiser use of the **Water Heater**
  - Scheduled and turned on only for the strictly necessary duration of time to obtain the water to be heated enough for when it is needed by the user
- **Washing Machine** and **Dish Washer** are rarely used during the week and at times very distant from the periods of non-peak hours



Simulation and Results

- **Annoyance rate->** Range of values from 1 to 5 modelled as a normal distribution with 15% deviation
  - value 1 is the minimum level of discomfort
  - value 5 is the highest level of discomfort



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Conclusion

- Results show that appliance scheduling can guaranteed energy savings, reducing consumptions of at least 49.2%
- Prediction of users' activities permitted a quite accurate scheduling based on probabilities
- It was possible to guarantee that the annoyance rate was never too high, respecting user comfort

Future Works

- There is the need to test the adaptability with different real-case scenarios and to improve prediction accuracies of next activities
- It will be evaluated how the presence of Renewable Energy Sources could affect the system
- Expand the system obtaining also information about user's health and finding the correlation between their right/wrong habits and their psycho-physical health

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Thank you for your attention

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