1.

- **Authors**: Theis Pedersen , Kasper Ubbe Nielsen, Steffen Petersen
- **Concept**: This paper presents a study on Room occupancy estimation . This paper generally is about the use of indoor climate sensor data for detection of occupancy .
- **Algorithms**: The paper uses ZLEMA filter, linear regression, exponential regression as well as occupancy detection rules in order to map the trajectory of collected data and detect the occupancy in the room.
- **Performance**: The paper uses ZLEMA to process the indoor climate sensor data which was collected earlier. Linear regression was used to determine the occupancy probability. Occupancy detection rules were kept in mind while using these algorithms.

  A set of rules were applied to the sensor data trajectory so that to detect room occupancy. Evaluation of proposed methods was done using sensor data from a test room and 3 room dorm environment.

- **Advantages**: The results show that occupancy detection allows more control of the HVAC systems. The proposed plug and play method for occupancy based on existing data is more cost effective since it is using already available sensor data .
- **Disadvantages**: The proposed method for occupancy detection faces limitations in accurately detecting the occupancy under different scenarios since different sensor types have different limitations and may not catch the occupancy effectively thereby affecting the energy saving potential.
- **Conclusions**: In the final stretch the paper concludes that the proposed methods offer a simple and operational approach without the need for extensive data . Because in this already

existing data is used and its results are comparable to the methods which are currently in use.

- **References**: L. Perez-Lombard, J. Ortiz, C. Pout, A review on buildings energy consumption information, Energy Build. 40 (2008) 394e398, http://dx.doi.org/10.1016/ j.enbuild.2007.03.007.

2.

- **Authors**: Adarsh Pal Singh, Vivek Jain, Sachin Chaudhari
- **Concept**: This paper presents a study on the usage of multiple heterogeneous sensor nodes as well as ml techniques for Room Occupancy Estimation. Performance of both homogeneous and heterogeneous are compared and data preprocessing as well as feature engineering techniques are also explored.
- **Algorithms**: The algorithms used in this paper are Linear Discriminant Analysis (LDA),Quadratic Discriminant Analysis (QDA),Principal Component Analysis (PCA) for performance evaluation, Random-Forest (RF).
- **Performance**: First of all Data is collected which consisted of more than 10000 points. After that feature engineering was applied which came out with co2 as a good indicator of no. of occupants.Then the above discussed algorithms were applied starting from LDA which uses gaussian distribution plus bayes rules to make predictions followed by QDA which allowed different covariance matricesfor each class.This was followed by SVM in order to use kernel for linearly separating classes.Then RF was uses which is a group of decision trees to come out with an outcome.

  After that heterogenous and homogeneous fusions phases were there followed by PCA analysis for performance evaluation.In the

end of the experiment performance was compared of both followed by the conclusion.

- **Advantages**: usage of PCA in occupancy estimation was promising since it was useful in capturing the underlying pattern in the data easily.This opened the doors for PCA to be used for real time scenarios.
- **Disadvantages**: co2 and sound sensors were used in this experiment.They require manual collaboratiobn to be done which is avery time consuming process
- **Conclusions**: parameters like accuracy,F1 score and confusion matrix were used to review the performance.according to the results a maximum accuracy of 98.4 was achieved with a F1 score of 0.953 for room occupancy.As dicussed earlier components like PCA were also used for performance evaluation.Thus the paper concluded by dicussing the future plans to take this pca analysis model to real-time scenarios i.e., larger workspaces.
- **References**: V. Garg and N. Bansal, “Smart occupancy sensors to reduce energy consumption,” Energy and Buildings, vol. 32, no. 1, pp. 81 – 87, 2000

3.

- **Authors**: Christos Sardianos , Iraklis Varlamis ,Christos Chronis, George Dimitrakopoulos
- **Concept**: This paper presents a study on Room occupancy estimation . The major focus is stressed upon room occupancy detection model which uses data from a motion sensor.
- **Algorithms**: The Room occupancy detection model uses cutting edge algorithms which rely on evidence as well as technology.It also includes various modules for data processing.

- **Performance**: Evaluation of room occupancy prediction model which uses data from a camera sensor shows a very low error rate However the proposed methodology which is generally based on motion sensor data showed a far better performance. It took a maximum of 5 to 15 minutes. The Room occupancy model aims at improving the energy efficiency in office buildings . hence for that the later seems a better fit.

- **Advantages**: The proposed model ensures that it maintains privacy of customers and follows its non-intrusive policies.
- **Disadvantages**: The proposed model based solely on motion sensor data can be very challenging.Moreover it is prone to errors since the absence of motion doesn't surely means that no one is there in the room.
- **References**: A. Alsalemi, C. Sardianos, F. Bensaali, I. Varlamis, A. Amira, and G. Dimitrakopoulos, "The role of micro-moments: A survey of habitual behavior change and recommender systems for energy saving," IEEE Systems Journal, pp. 1–12, 2019

4.

- **Authors**: Claudia Chit, Grigore Stamatescu, Alberto Cerpa
- **Concept**: This paper is about estimating occupancy in a building using sensor data and various other learning techniques. The research done aims at improving the efficiency of HVAC systems in buildings.
- **Algorithms**: This paper makes use of two algorithms for estimating occupancy i.e., Random-Forest(RF) and K-Nearest Neighbours(KNN).
- **Performance**: The evaluation of the performance of the two algorithms is done based on the Root mean square error(RMSE) which shows that the RF algo can achieve RMSE anywhere from

3.10 to 11.21 while the KNN algo has its own RMSE ranging between 2.96-8.46.

The performance analysis of this paper shows the potential these algorithms have in occupancy estimation and the average occupancy errors lying between 5-16 occupants.

- **Advantages**: The framework developed can be integrated with the Building Management Systems(BMS) thereby allowing for improved terms of energy efficiency.
- **Disadvantages**: One of the major problems is lack of the dedicated counting devices which obstruct the occupancy estimation process.
- **References**: V. L. Erickson, M. Á. Carreira-Perpi ̃n án, and A. E. Cerpa, "Ob-serve: Occupancy-based system for efficient reduction of hvac energy," in Information Processing in Sensor Networks (IPSN),2011 10th International Conference on. IEEE, 2011, pp. 258–269

5.

- **Authors**: Charles Leech, Yordan P. Raykov, Emre Ozer, Geoff V. Merrett

- **Concept:** The paper focuses on the implementation and deployment of a parametric Bayesian machine learning algorithm on microcontrollers that estimates room occupancy.

- **Algorithms:** The paper implements Bayesian machine learning on MCU(Microcontroller unit) to estimate the room occupancy. It also uses the iterative MAP inference method to fit the streams of PIR data.

- **Performance:** The algorithm shows a significant reduction in chip memory usage in MCUs through machine learning models. When used with the high-performance MCU there is a 19x improvement in execution time.

- **Advantages:** The algorithm optimizes memory usage and provides real-time acceptable performance consuming less energy. It uses PIR sensors making it cost-effective and a good solution in smart rooms.

- **Disadvantages:** The algorithms use memory-intensive operations limiting their deployment to a few MCUs. Low-end MCUs do not meet requirements all the time.

- **Summary:** The paper focuses on a parametric Bayesian machine learning algorithm on microcontrollers estimating room occupancy in a smart room

- **References:** IEEE Instrumentation and Measurement Society, & Institute of Electrical and Electronics Engineers. (n.d.). 2017 IEEE Sensors Applications Symposium : 2017 proceedings papers : Glassboro, New Jersey, USA, March 13-15, 2017.

6.

- **Authors**: Zhenghua Chen, Chaoyang Jiang, Lihua Xie
- **Concept:** The Artificial Neural Network(ANN) and Support Vector Machine algorithms were employed to analyze and process data from various sensors for room occupancy estimation. The Hidden Markov Model(HMM) was used to get correlations between

different sensors resulting in better performance in estimating the room occupancy.

- **performance:** The results showed the superiority of the deep learning approach which used a convolution deep bidirectional long short-term memory network for occupancy estimation.

- **Advantages:** The data mining methods Artificial Neural Network(ANN) and Support Vector Machine(SVM) used offer accurate results and enable more comprehensive occupancy estimation.

- **Disadvantages:** PIR sensors can only detect motion and miss many static or idle occupants.
- Modeling may require complex ML techniques.

- **Summary:** Building occupancy estimation and detection using various sensors to detect CO2, temperature humidity, and WIFI signals estimate occupancy in a given room.

- **References:** Chen, Z., Jiang, C., & Xie, L. (2018). Building occupancy estimation and detection: A review. In Energy and Buildings (Vol. 169, pp. 260–270). Elsevier Ltd. https://doi.org/10.1016/j.enbuild.2018.03.084

7.

- **Authors:** Manar Amayri, Abhay Arora b, Stephane Ploix, Sanghamitra Bandyopadhyay, Quoc-Dung Ngo, Venkata Ramana Badarla

- **Concept:** This paper proposes a general approach to estimate the number of people in a room using a heterogeneous sensor environment. It involves determining the most useful measurements and decision tree learning for estimation.

- **Algorithms:** A data mining learning process using the RapidMiner program and random forest algorithm was proposed to extrapolate office occupancy patterns. Methods were introduced to model occupant behaviour and quantify its impact on building energy use which is used for estimation.

- **Performance:** The random forest algorithms applied in an office setting gave an error of 0.19-0.18 while the decision tree gave an accuracy of 96% where occupancy did not exceed 2 persons.

- **Advantages:** This approach utilizes machine learning and decision trees making it easily readable while being transparent and interpretable in estimation. It considers many measurements like CO2 concentration, microphone, door positions, etc.

- **Disadvantages:** Overfitting issues were discussed indicating the need to address potential problems related to complexity.

- **Summary:** It is a general approach to estimating the number of people in a room using a heterogeneous environment. It uses decision tree learning algorithms and rapid-miner considering factors such as CO2 concentration, microphone, door positions, etc. This paper aims to simplify the analysis of occupancy estimation and identify the most relevant sensor sets for best results.

- **References:** Amayri, M., Arora, A., Ploix, S., Bandhyopadyay, S., Ngo, Q. D., & Badarla, V. R. (2016). Estimating occupancy in heterogeneous sensor environment. Energy and Buildings, 129, 46–58. https://doi.org/10.1016/j.enbuild.2016.07.026

8.

• **Authors:** Chaoyang Jiang , Zhenghua Chen, Rong Su , Mustafa Khalid Masood, Yeng Chai Soh

• **Concept:** The paper is based on Bayesian filtering for building occupancy estimation from carbon dioxide concentration observations.The effectiveness of the proposed method is demonstrated through real experiment results.

•**Algorithms:** The paper utilises a Bayesian filtering framework for building occupancy estimation.The Bayes filter technique is applied to fuse the transition probability.Transition probability matrices are calculated based on the occupancy levels and the first-order Markov process assumption.

• **Performance:** The proposed framework based on Bayesian filtering for building occupancy estimation shows improved performance compared to the observation model alone.The solution outperforms the results of the observation model, indicating the effectiveness of the proposed method.

• **Advantages:** The observation model estimates occupancy levels from carbon dioxide concentration, providing valuable information for occupancy estimation .The proposed framework utilises Bayesian filtering, which allows for the fusion of a statistical model and an observation model, resulting in improved occupancy estimation .

• **Disadvantages:** Their might be privacy concerns because we are monitoring the behaviour and movements of individuals. Bayesian filtering method might be sensitive to external factors and CO2 sensors require high maintenance.

• **Summary:** The proposed methods groups extreme learning machine techniques help identify the observational model. By combining the transition

probability and likelihood, the framework outperforms the results of the observation model.

• **References:** J. Laustsen , Energy Efficiency Requirements in Building Codes, Energy Efficiency Policies for New Buildings, International Energy Agency (IEA), 2008 .

9.

• **Authors**: Chaoyang Jiang, Mustafa K. Masood, Yeng Chai Soh, Hua Li

• **Concept:** This paper focuses on the indoor occupancy based on carbon dioxide concentration and highlights the issue on CO2 measurement and suggests pre smoothing the CO2 data which can improve the accuracy.

• **Algorithms:** The paper uses Feature Scaled Extreme Learning Machine (FS-ELM) algorithm for identifying the dynamic model of occupancy level estimation and use of smoother for image signal edge-preserving smoothing.

• **Performance**: This paper has a new criterion called x-tolerance accuracy to assess the performance of the proposed occupancy estimator. The accuracy of the estimator is up to 94% with a tolerance of four occupants.The collected occupancy data used as ground truth for evaluation is reported to be almost exact, as all the calculated occupancy levels of the 30 days are zero after 11:30 pm.

• **Advantages:** The use of the Feature Scaled Extreme Learning Machine (FS-ELM) algorithm improves the performance of the occupancy estimation in terms of Root Mean Square Error (RMSE).The paper provides a solution for real-time applications where globally smoothed CO2 data is unavailable by using locally smoothed CO2 data instead.

• **Disadvantages:** This paper include the potential impact of CO2 concentration spikes on estimation accuracy and the potential accumulated error when using locally smoothed CO2 data instead of globally smoothed data.

• **Summary:** The proposed occupancy estimator was tested in an office room with 24 cubicles and 11 open seats, achieving an accuracy of up to 94% with a

tolerance of four occupants. The paper introduces a generalised discrete-time state space model.

• **References:** L.M. Candanedo, V. Feldheim, Accurate occupancy detection of an office room from light, temperature, humidity and CO2 measurements using statistical learning models, Energy Build. 112 (2016) 28–39.

10.

• **Authors:** M.S. Zuraimi , A. Pantazaras, K.A. Chaturvedi, J.J. Yang, K.W. Tham, S.E. Lee • Concept:This paper focuses on the occupancy estimation in a lecture hall based on CO2 measurements using physical and statistical models.

• **Algorithms:** Dynamic mass balance model, Support Vector Machines (SVM), Artificial Neural Networks (ANN) and Feedforward ANN uses the Sigmoidal function as the transfer function.

• **Performance:** The RMSE values for the SVM, ANN, and dynamic physical models were 12.6, 12.1, and 12.8 respectively, indicating their accuracy in predicting occupancy counts.The correlation coefficients for all the models were greater than 0.95, further confirming their predictive performance. The average accuracy of all models is around 70% and 76%.

• **Advantages:** The dynamic mass balance model showed good agreement with ground truth data. SVM and ANN shows higher predictive performance in occupancy count prediction.This paper provides merits and limitations of each model, offering guidance on using various models.

• **Disadvantages:** The physical models do not consider the effects of temperature sensors on air exchange rate dynamics and do not handle multi-zone spaces with multiple air handling units serving the same zone. We require additional sensors to detect zero room occupancy.

• **Summary:** Both physical and statistical models showcased good performance in predicting occupancy counts for a large number of occupants.future work is needed to investigate how the models can be improved to accurate detection of the occupancy presence in buildings.

• **References:** ASHRAE 62.1, ASHRAE standard 62.1 Ventilation for Acceptable Indoor Air Quality, Atlanta, 2013