

COPOLAN: Non-Invasive Occupancy Profiling for Preliminary Assessment of HVAC Fixed Timing Strategies

Abstract

Nowadays, control of heating, cooling and ventilation equipment operation is mainly achieved via timers with fixed setback schedules, configured using experience and standard models of space occupancy. Applying generic timing strategies is however rarely optimal. Sensor-based systems offer a solution for dynamic control of equipment operation using real-time space occupancy input, but both deployment time and cost constraints hinder their integration if savings and return on investment are uncertain. This work introduces COPOLAN, a tool that correlates power consumption patterns and computers' VLAN activity. Utilising computers' VLAN activity auditing is key to obtain the power state of employees' computer equipment over time, a prime indicator of employees' presence within a building. At low cost and non-invasively, COPOLAN uncovers misalignment and produces ground for (1) determining opportunities of improving HVAC timing strategies and (2) helping decision making prior to integrating new equipment such as sensor-based systems. COPOLAN has been experimented on within a University department, where misalignment between power consumption and space occupancy patterns have highlighted 10 % energy saving opportunities.

1 Introduction

Office buildings are environments in which daily loads resemble the load shown in Figure 1. Nighttime hours exhibit a steady base load, while daytime hours show load increase due to equipment activation within the building. Analysis of electric load shapes generally focuses on the calculation of a wide variety of statistics, such as base load, peak load, and duration of high load [7]. Load shape analysis is traditionally conducted by utilities to obtain historical data and forecast accurately future power requirements of a given building. Such statistics are used within this paper for corre-

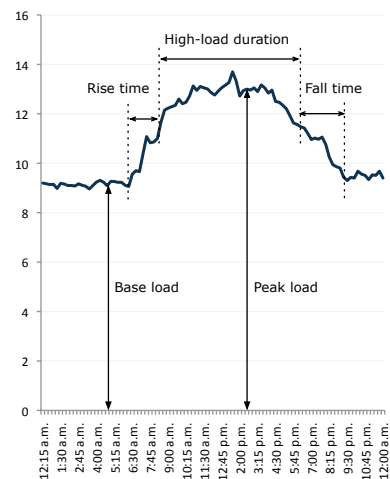


Figure 1. Minimum set of parameters recommended by Price et al. for characterising load shapes [7].

lation with building occupancy patterns in order to produce a preliminary assessment of loads' operational schedules, and identify quickly at low cost and disruption opportunities to fine tune those schedules.

Heating, ventilation and air conditioning (HVAC) equipment has a major contribution to the overall daily load [3]. Within buildings that can afford it, building management systems (BMS) assist facility managers for controlling this source of energy spending, providing solutions to visualise and control equipment operational state from a remote centralised location. Facility managers can set operational schedules via timers, i.e. configure centrally start-up and switch-off times for each piece of equipment, increasing overall control over a site's energy spending. In other sites, timers can be deployed and controlled locally to adjust machines' operational patterns.

Timers settings impacts the buildings energy efficiency and operational cost. Timers are generally configured using weather conditions and insights on space occupancy. Depending on the availability of weather and occupancy monitoring systems, timers are continuously adjusted in near real-time or assigned with static values using historical data, models and experience. Fixed timing strategies are often not optimised to the building, where peculiar occupants and

business activities differ from generic models. .

Sensor-based systems offer a solution for dynamic control of equipment operation using real-time space occupancy input, but both deployment time and cost constraints hinder their integration if savings and return on investment are uncertain. This work introduces COPOLAN, a tool that correlates power consumption patterns and computers' VLAN activity. Utilising computers' VLAN activity auditing is key to obtain the power state of employees' computer equipment over time, a prime indicator of employees' presence within a building. At low cost and non-invasively, COPOLAN uncovers misalignment and produces ground for (1) determining opportunities of improving HVAC timing strategies and (2) helping decision making prior to integrating new equipment such as sensor-based systems.

Section 2 gives background information on HVAC timing strategies and space occupancy monitoring, motivating the need for a tool capable of quickly assessing optimisation opportunities prior to introducing complex control strategies. Section 3 describes the methodology and processing steps used in COPOLAN for assessing the need for better HVAC control strategies. Section 4 presents results from a case study in which COPOLAN is experimented. Finally, Section 5 concludes.

2 Related Work

Depending on the geographic location, heating and cooling in office buildings have different guidelines. For instance, in Ireland, the heating season extends for a period of about 220 to 260 days, from mid autumn through the winter and into late spring, whereas cooling season has not been a requirement in Ireland's temperate climate [4]. Office buildings also have unique heating and cooling requirements depending on the business and staff work schedules, e.g. government buildings may exhibit different work hours than banks and University departments. Therefore, setting timers is a matter unique to each building.

Optimal operating schedules for HVAC equipment should set start time to be as late as possible and stop times to be as early as possible while maintaining comfort points for occupants. Various degrees of timing control are available, from purely static on and off times, to more complex control algorithms refining operating time schedules dynamically based for example on weather conditions, day of the week, and localised space occupancy.

Whilst static timing control is generally configured using experience and valid assumptions, e.g. ASHRAE Standard 90.1 occupancy models [2], alignment with space occupancy is not guaranteed and timer strategies need to be assessed. Newsham et al. [6] proposed a system that gathers measurements from deployed wireless sensor nodes and network login and activity information in order to assess a building occupancy. Both deployment of wireless sensor nodes and distributed software agents provided accurate and localised reports on individuals presence, which are very useful for fine-tuning HVAC timing strategies. Similarly, both dynamic control [1] algorithms and occupancy prediction models [5] can be implemented using a deeply coupled network of sensors and actuators. However, for existing HVAC equipment,

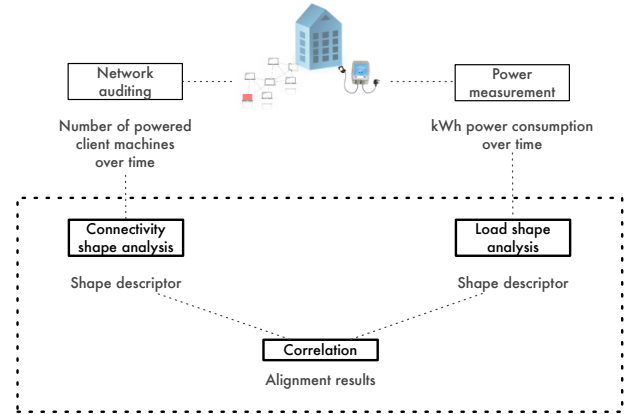


Figure 2. Concurrent power measurements and VLAN audit data are analysed to identify the correlation between load activation and space occupancy.

calibration complexity and deployment costs may be obstacles to widespread adoption if savings and return on investment are not guaranteed. While modern equipment will incorporate technology for local assessment whether activity is required, most buildings currently utilise equipment that cannot yet provide such feature. Building managers are therefore in a situation where efficiency of HVAC equipment operation is unknown and potential savings uncertain, possibly missing opportunities to optimise timer setback schedules via the introduction of real-time occupancy monitoring systems.

A preliminary assessment of opportunities to reduce power consumption can significantly improve HVAC fixed timer strategies and help decision making for installing occupancy-based control of HVAC equipment. With COPOLAN, this paper proposes a tool capable of evaluating the potential saving opportunities of a given building non-invasively, quickly, and a low-cost, prior to engaging in more accurate but more complex control systems.

3 Methodology

The following describes how shape descriptors are used and processed to extract load/space occupancy alignment results.

3.1 Correlation of shape descriptors

Load shape analysis simplifies load measurements by producing shape descriptors, sets of data points carrying important shape information. For instance, shape descriptors contain times at which a load rises from and falls back to its baseline after-hours state. This work aims to characterise occupancy similarly, analysing the curve plotting the number of client machines connected to a building's VLAN over time. Load and connectivity shape descriptors can then be correlated and provide preliminary insights on whether timer strategies of HVAC equipment can be improved, as depicted in Figure 2.

Figure 3 shows power consumption and client machines' connectivity measurements, retrieved simultaneously in a University building. The proposed technique makes use of the two streams of raw data only to derive the correlation

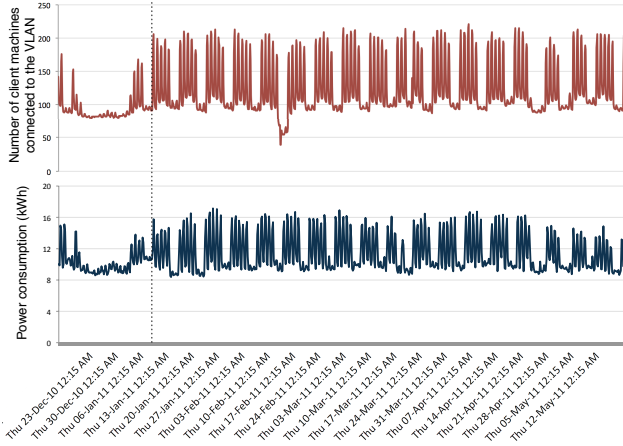


Figure 3. KWh power consumption and number of client machines connected to the [anonymised] University School’s VLAN over a 5-month period.

between load activation and space occupancy, therefore preventing any invasiveness and deployment constraints. As shown in Figure 4, COPOLAN makes use of five time points to compose for each day the shape descriptors of each curve, and to later compare evolution of power consumption and space occupancy. The following describes the five time points:

1. T_{start} is the time at which activity starts, e.g. client machines appear on the VLAN after being powered on by people arriving to work;
2. T_{max} is the time at which maximal activity is measured, e.g. time when the load reaches its maximal power consumption;
3. $T_{high-load/occupancy\ start}$ is the time at which load and space occupancy go over half of their maximal activity;
4. $T_{high-load/occupancy\ end}$ is the time at which load and space occupancy return below half of their maximal activity;
5. T_{end} is the time at which activity ends, e.g. power consumption and number of connected client machines is equal to the nighttime level.

3.2 Processing and analysis

Using solely power consumption readings and machine activity reports, COPOLAN’s intelligence lies in the processing and analysis of raw data, to extract alignment results and convert them into saving opportunities. The following describes COPOLAN processing and analysis steps highlighted in Figure 5—the same steps apply for both data inputs but the following utilises power consumption terms to illustrate.

1. The first step consists of running a script through the entire data set to capture for each day T_{start} and T_{max} time points, as well as calculating the evening base load value. The evening base load value is calculated as equal to the average power consumption of the 10pm-11pm time slot. Similarly, the morning base load V_m

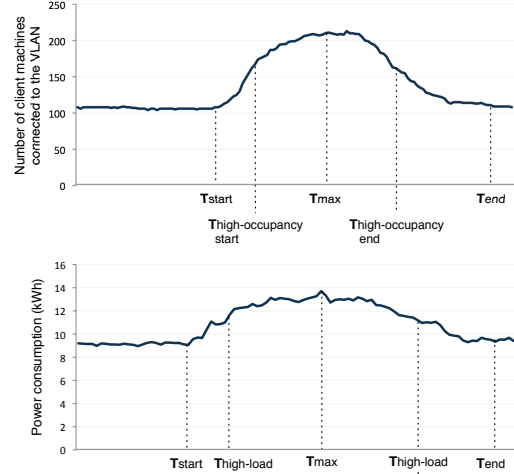


Figure 4. Illustration of the five time points measured for each day of the audit for analysing whether space occupancy has evolved over time.

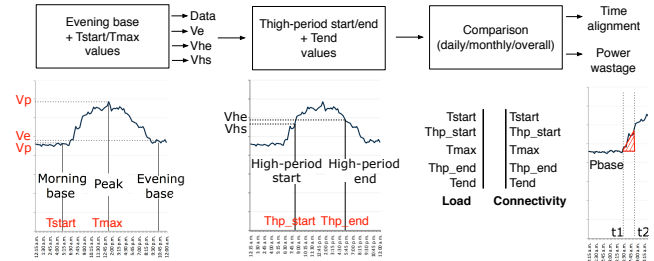


Figure 5. Illustration of COPOLAN’s processing and analysis steps.

value is calculated as equal to the average power consumption of the 5am-6am time slot, and T_{start} is measured as the time the load goes over the morning base load. Over a day, the value of T_{max} is updated every time a power consumption value observes a maximum. Finally, the power consumption V_p at T_{max} is recorded, and used to calculate V_{hs} and V_{he} , the power consumption values that will indicate when the load is in its high-load period (going over $V_m + (V_p + V_m)/2$ and going below $V_e + (V_p + V_e)/2$).

2. The second step consists of running scripts through the entire data set another time to capture for each day $T_{high-load/occupancy\ start}$ and $T_{high-load/occupancy\ end}$ corresponding to the times at which V_{hs} and V_{he} recorded power consumption values appear. Besides, the script records T_{end} as the time the load decreases to within the evening base load value.
3. After two script iterations, shape descriptors for both the load and connectivity curves have been produced. Correlation is then realised with multiple options. Descriptors can be compared per day, week, month or per the entire audit period depending on the insights of interest for the user.

Table 1. Operational schedules of equipment controlled via timers within a University department.

New part of building	Monday - Friday
Air Handling Units	
All toilets	8am-10pm
Theatre	8am-10pm (enabled)
Ground floor computer rooms	8am-10pm
1st floor computer rooms	8am-10pm
Fan coil units	8am-10pm
Radiator circuits	7am-7pm
Entrance convector	8am-7pm
Domestic hot water	8am-7pm
Toshiba cooling units (x4) (+ manual control)	8am-7pm
Old part of building	Monday - Friday
Radiator circuits	7am-6pm
Domestic hot water	7am-6pm

- The last step consist of displaying (1) time alignment results showing the average time points for both curves over the specified period, and (2) the estimated power that could be saved, equal to $\int_{t_1}^{t_2} P(t)dt - (t_2-t_1)P_{base}$.

4 Experimentation

Electricity readings and networked equipment activity were acquired for a period of 5 months within the School of Computer Science and Informatics, at [anonymised]. Data has been used to illustrate how timer schedules are performing against space occupancy.

4.1 HVAC equipment and measurement setup

The University Department is equipped with the HVAC equipment presented in Table 1, controlled by timers set via an BMS by the University Building & Services department. A survey of facility managers of the University highlighted that the primary assumption when defining the timer schedules was that building occupancy was from 8am to 6pm. Radiator circuits are configured to start one hour before building occupancy, whereas other equipment is triggered at 8am. Timers' strategy for switch-off times is however not consistent, highlighted with the differences between the old and new parts of the buildings. Those observations over timer settings already provide insights that the timer strategy has no solid ground.

In order to have an accurate profile of power and occupancy, measurements of power consumption and VLAN auditing were realised with (1) a SOCOMEC Modbus 3-phase meter with a sampling frequency of one sample per 15 minutes, and (2) a PC-class machines sending network probes over the VLAN to capture the number of client machines powered on over time. The VLAN auditing technique is similar to the one discussed in [8].

4.2 Reducing analysis complexity

Analysis complexity increases with the size of the data set. Complexity of timing strategy analysis can be reduced in case both power consumption and space occupancy patterns are regular over the monitored period. As discussed previously, this work investigates the correlation of five time points retrieved via shape analysis. A preliminary work is therefore to determine whether those five time points change

over time for both curves, and subsequently if they allow results derived from a smaller data set to be generalised to the entire data set. In order to achieve this, the following section provides insights on the evolution of space occupancy and power consumption patterns over the 5-month audit period.

4.2.1 Evolution of space occupancy patterns

Shape analysis applied to the curve plotting the number of client machines' powered on over time allows analysis of whether space occupancy evolved over the 5-month audit. The five time points that characterise the evolution of space occupancy over a day have been measured for each business day over the 5-month audit period (week-ends have been removed), and results are shown in Figure 6.

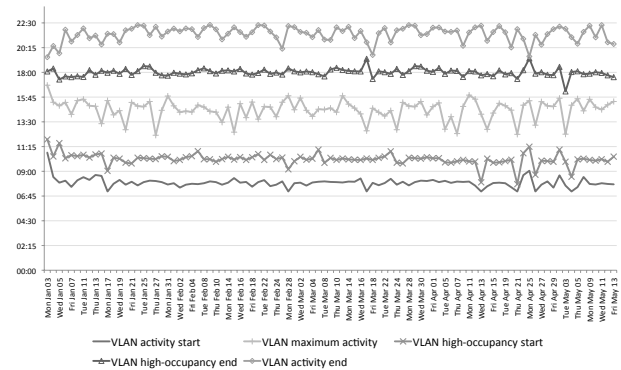


Figure 6. Evolution of the five time points that characterise space occupancy over each day of the 5-month audit period.

As depicted in Figure ??, results show time constancy for the five time points with no increase/decrease trends, apart from a few outliers. After investigation, days when important differences appeared were bank holidays, such as Easter on April 22-25, and May day on May 2, when few machines were operated. This demonstrates that the way the building is occupied varies little over different week days and over different seasons.

4.2.2 Evolution of power consumption patterns

Shape analysis applied to the power consumption allows analysis of whether power consumption patterns evolved over the 5-month audit. The five time points that characterise the evolution of power consumption over a day have been measured for each business day over the 5-month audit period, and results are shown in Figure 7.

Similarly to space occupancy patterns, results show constancy for the five time points with no increase/decrease trends, apart from outliers on bank holidays.

4.2.3 Generalisation

Based on the evolution of power consumption and space occupancy patterns, we can generalise results as follows. Space occupancy and power consumption shape descriptors showed no important discrepancies in the five time points for each business day of the 5-month audit. Such indication allows for the present case study to analyse correlation of shape descriptors over a short time period and generalise results to the entire audit period. In the following, time point

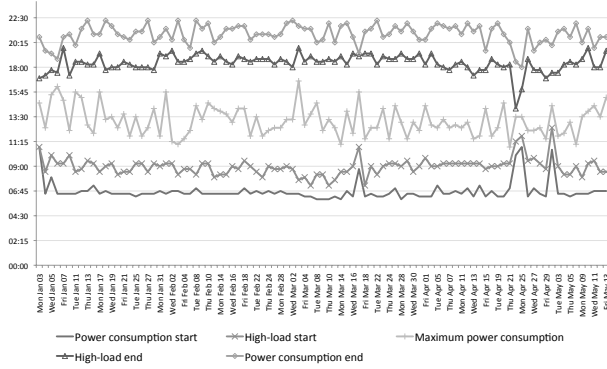


Figure 7. Evolution of the five time points that characterise space occupancy over each day of the 5-month audit period.

correlation of load and connectivity shape descriptors is investigated over two reduced data sets.

4.3 Correlation between load activity and space occupancy

Figure 8 and 9 illustrate the correlation between load activity and space occupancy, The study focuses on two sets of data: the first Tuesday of each month and a week in May, respectively, in order to cover correlation over different seasons and different days of the week. Results discussed in the following are generalised to the entire audit data, as both space occupancy and power consumption patterns were shown to vary little over time.

Figure 8 superposes measurements of space occupancy and power consumption of the University department for the five first Tuesdays from January to May 2011, in order to investigate whether correlations change over different seasons. Load rise and occupancy start and end times have been highlighted for comparison, as well as high-occupancy and high-load durations.

First observations confirm that space occupancy appear very similar for each Tuesday, except for January, 4, 2011 when few people came to work after the Christmas break. Load shapes show differences in their kWh power consumption amplitudes, but rise/fall times are identical as well as high-load start/end and high-load durations. Furthermore, space occupancy starts at 8am for each Tuesday, but high-occupancy only starts around 10am. In contrast, load rise starts around 6:15am and high-load at 8:30am. Besides, high-occupancy lasts from 10am to 5:45pm, whereas high-load lasts from 8:30am to 6:15pm. Finally, both space occupancy and power consumption exhibit a decreasing slope starting from 4:30 and reaching baseline level at 10pm.

Figure 9 superposes measurements of space occupancy and power consumption of the University department for five consecutive business days in the 2nd week of May 2011, in order to investigate whether correlations change depending on the day of the week. Observations similar to those made for the first Tuesdays of each month are highlighted, showing similar timings for both shape descriptor time points.

Finally, Table 2 provides averages of the five time points

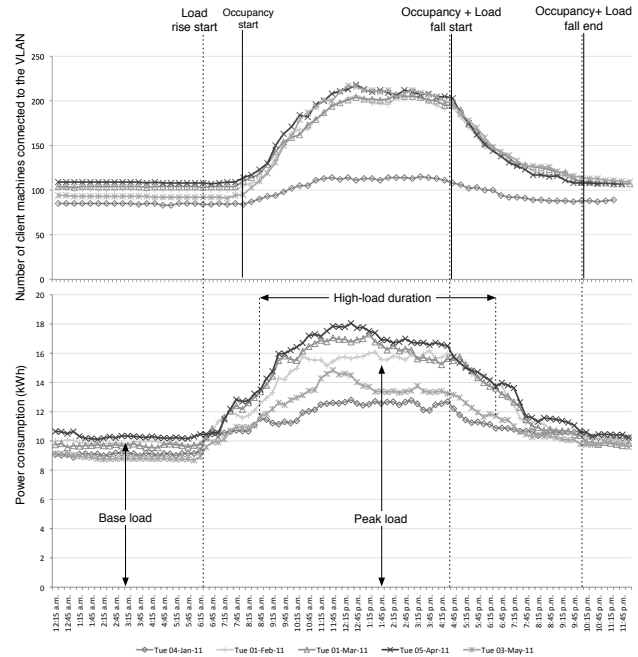


Figure 8. Illustration superposing space occupancy and power consumption for the first Tuesdays of January, February, March, April and May 2011.

Table 2. Operational schedules of equipment controlled via timers within the School of Computer Science and Informatics.

	Start	High-period start	Max	High-period stop	End
Power consumption	06:34	08:57	13:09	18:23	21:00
Space occupancy	07:58	10:06	14:36	18:00	21:29

measured for each descriptor of each day over the 5-month audit period. Those results confirm the timing insights given from the visual load shape analysis.

4.4 Discussion

Shape analysis applied to measurements of power consumption and networked equipment activity over the VLAN have provided the following information:

- Space occupancy start/end times did not change over seasons or over the day of the week;
- Load rise and fall times did not change over seasons or over the day of the week;
- Space occupancy recurrently started 1h30 after load rise start;
- Space high-occupancy started 1h15 after the building entered its high-load period;
- Space high-occupancy lasted 2 hours less than the high-load period;
- Space occupancy and power consumption decreased concurrently (same start/end times).

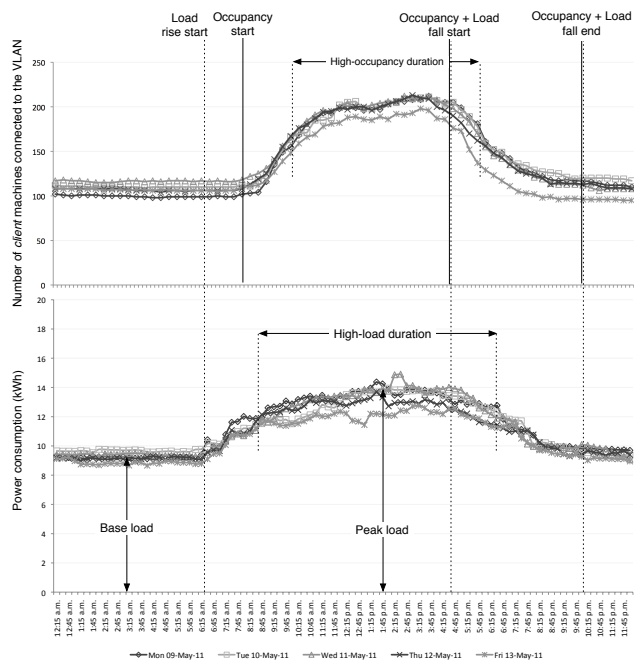


Figure 9. Illustration superposing space occupancy and power consumption for each day of a week in May 2011.

Those results help uncover opportunities for changing the timers' strategy in the University building. HVAC equipment is switched on too early in the building, but appears to turn off at the right time. Delaying a workplace equipment start-up time by one hour means that a building operates at capacity for one hour less a day. The high-load period lasting almost 10 hours, gains within the University department would then represent a 10 percent decrease in energy consumption and associated costs. Those results, obtained non-invasively and at low-cost, provide an initial assessment on gains that can be achieved with optimised HVAC equipment control, and which can motivate a re-dimensioning of timing strategies or the integration of equipment for dynamic HVAC control.

Analysing the identity of client machines connected to the VLAN would push further the assessment of HVAC control strategies, providing insights of gains that could be obtained during daytime hours. Client machines have unique MAC addresses, and breaking the building space occupancy down to sub areas with known MAC addresses, e.g. classroom or offices where MAC addresses of networked equipment would be retrieved, would provide localised occupancy profiles and insights on optimisation opportunities.

Finally, a bigger picture with multiple University buildings exhibits unique power consumption patterns for each building. Figure 10 shows power measurements taken within the Computer Science, Veterinary, Health Science departments and the Library at [Anonymised]. Load rise and fall times as well as the high-load period of the Computer Science have been inserted on the graph for comparison. Interestingly, rise and fall times seem similar for all sites at 6am

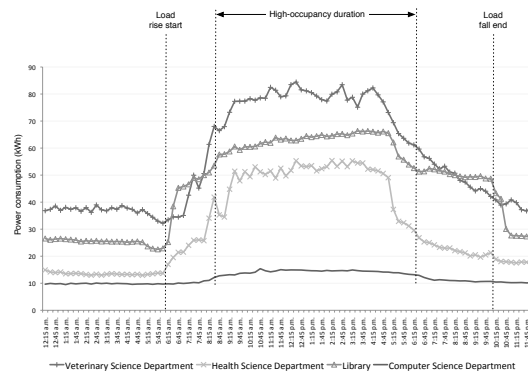


Figure 10. Illustration showing that shapes of power consumption vary depending on the building's activity.

and 10pm. However, important power steps denote different activity patterns within those departments. This highlights opportunities for VLAN/Power correlation to demonstrate whether better timer strategies could be put in place.

5 Conclusion

Strategies for setting timers controlling HVAC equipment operation generally rely on experience and models when measurements of building occupancy are unavailable. Sensor-based occupancy monitoring systems are enablers for optimised equipment scheduling, but deployment time and cost constraints hinder their widespread integration when gains are uncertain. This work has introduced COPOLAN, a novel technique correlating power consumption and VLAN machine activity to provide insights on deployed timing strategies, and highlight gains that could be obtained with optimised timer setback schedules. The non-invasive technique may be used as stand-alone or prior to deciding whether to replace equipment or install occupancy sensors. Experimentation within a University department has shown opportunities to delay equipment start-up time by one hour, highlighting up to 10% potential savings with better timer setback schedules.

6 Acknowledgments

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7 References

- [1] Y. Agarwal, B. Balaji, R. Gupta, J. Lyles, M. Wei, and T. Weng. Occupancy-driven energy management for smart building automation. In *BuildSys'11*.
- [2] ASHRAE. standard 90.1: Energy standard for buildings except low-rise residential buildings. In *ASHRAE, Inc.*, 2007.
- [3] E. I. A. Department of Energy. Building end-use consumption survey. 1999.
- [4] H. Department of the Environment and L. Government. Energy efficiency in traditional buildings. 2010.
- [5] V. Erickson, M. Carreira-Perpinan, and A. Cerpa. In *IPSN'11*.
- [6] G. R. Newsham and B. J. Birt. Building-level occupancy data to improve arima-based electricity use forecasts. In *BuildSys'11*.
- [7] P. Price. Methods for analyzing electric load shape and its variability. volume LBNL-3713E, 2010.
- [8] A. Schoofs, A. Sintoni, A. G. Ruzzelli, and G. M. P. O'Hare. Netbem: business equipment energy monitoring through network auditing. In *BuildSys'11*.