Literature Review of Water Consumption Data Analytics

Water Data Analysis

- Outliner Analysis
  - Data acquisition problems
  - Pipe busts, leaks and anormal consumption
- Water Consumption Analysis
  - Socio-demographic, billing and infrastructure analysis (descriptive analysis): Analyze from different dimesions: time (hourly, daily or monthly, season) customer, customer group, location, etc.
  - Consumption pattern discovery (summer, winter, day and night consmption);
  - Clustering
- Water Consumption Modeling
  - Model demand with climate effect;
  - Forecast model

Paper 1: Quantifying the influence of residential water appliance efficiency on average day diurnal demand patterns at an end use level: A precursor to optimised water service infrastructure planning *(Byron et al., Griffith University, Australia, 2012)*

- Research Objectives
  - Develop the weighted classfication method to cluster household based on the warter stock effciency (i,e., shower, clothes washer, tap and toile)
  - Discover the average daily demand pattern
- Study Method
  - Data: 191 household hourly diurnal water consumption in two weeks
  - Calculate the overall efficiency (*composite star rating)* using the weighted primary end use.

Household efficiency distribution in terms of overall star rating

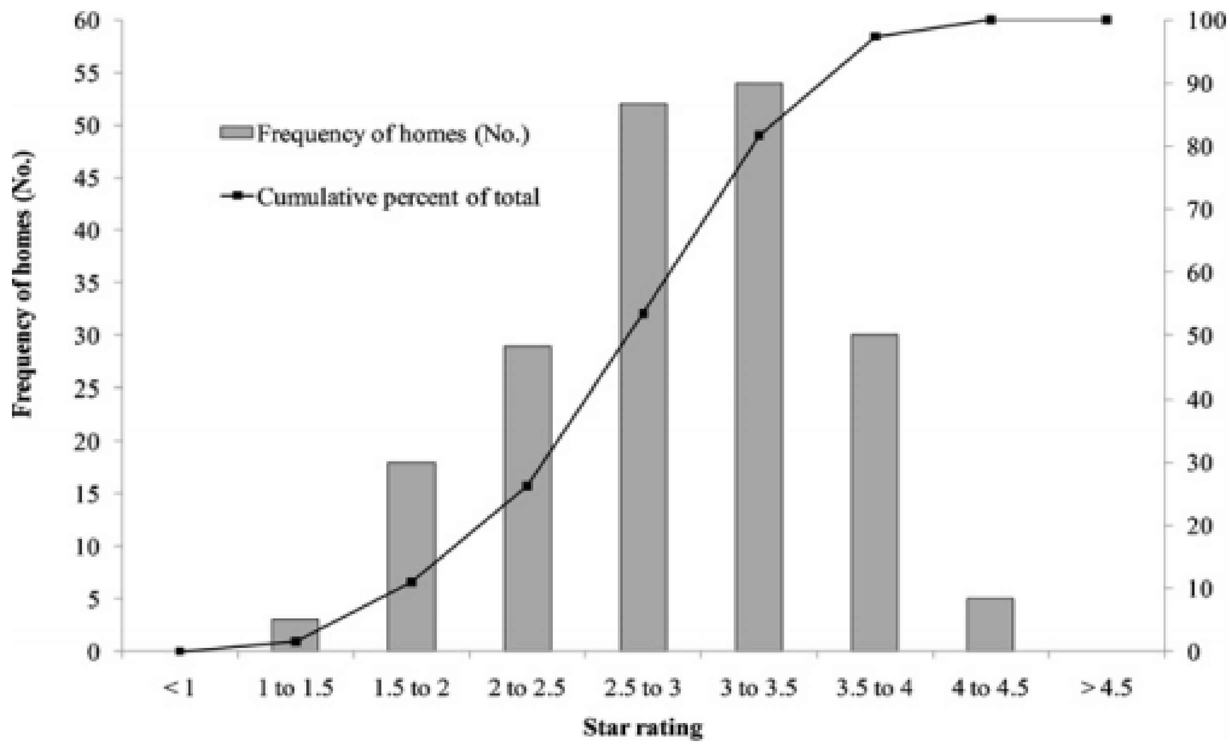
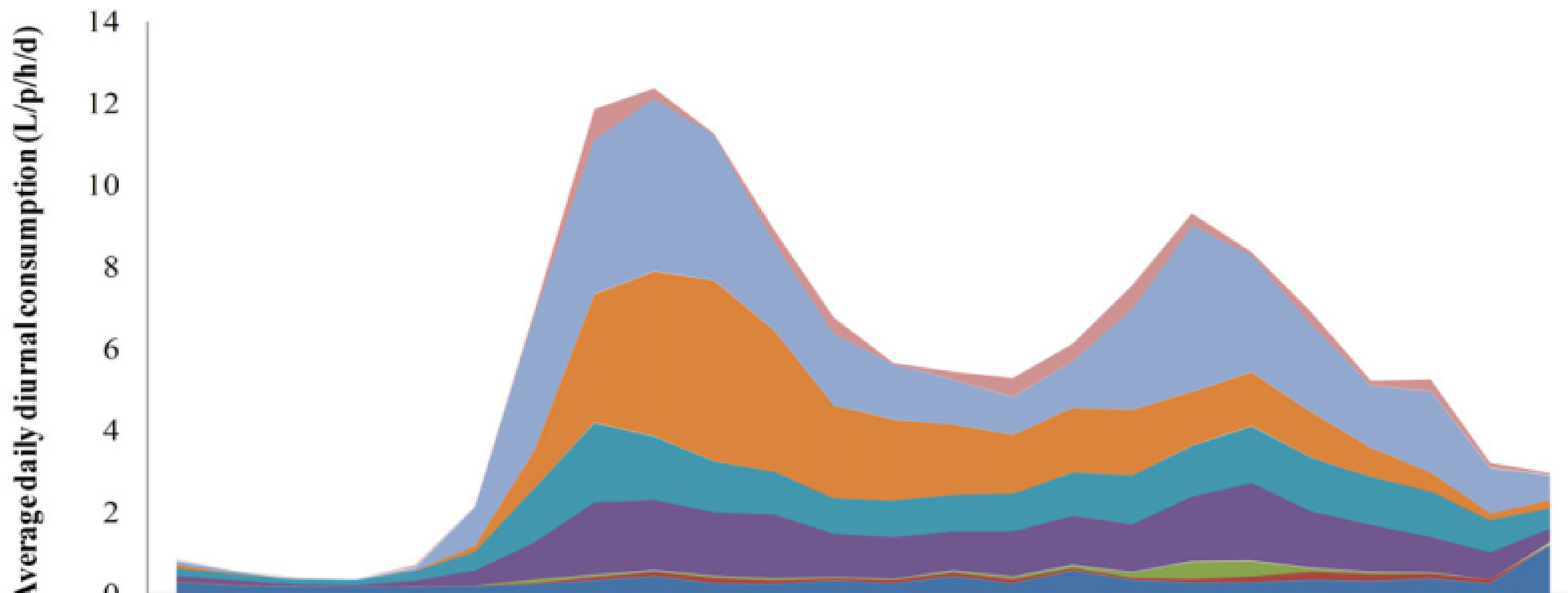


Fig. 2. Household efficiency frequency distribution.

3.3. AD diurnal demand pattern generation and statistical analysis

The disaggreted consumption pattern

1. The average daily diurnal demand pattern for households with a less than three start rating



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Irrigation	0.02	0.00	0.02	0.00	0.04	0.01	0.11	0.75	0.26	0.03	0.29	0.40	0.03	0.19	0.46	0.42	0.58	0.30	0.09	0.30	0.11	0.29	0.11	0.04
Shower	0.09	0.06	0.00	0.01	0.08	0.95	3.31	3.79	4.23	3.56	2.16	1.75	1.35	1.08	0.92	1.13	2.45	4.06	2.85	2.14	1.52	1.97	1.10	0.61
Clothes Washer	0.08	0.01	0.00	0.00	0.01	0.15	0.93	3.12	4.02	4.42	3.44	2.28	1.97	1.73	1.44	1.58	1.60	1.31	1.31	1.10	0.71	0.46	0.18	0.19
Toilet	0.22	0.16	0.13	0.14	0.26	0.47	1.33	1.96	1.56	1.25	1.07	0.87	0.90	0.90	0.93	1.07	1.21	1.25	1.39	1.32	1.18	1.13	0.79	0.51
Tap	0.14	0.11	0.05	0.05	0.15	0.38	0.93	1.79	1.74	1.58	1.58	1.07	1.04	0.97	1.12	1.22	1.18	1.60	1.92	1.39	1.16	0.88	0.68	0.35
Bathtub	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.06	0.03	0.05	0.05	0.03	0.03	0.05	0.07	0.07	0.14	0.44	0.39	0.09	0.06	0.02	0.00	0.03
Dishwasher	0.02	0.02	0.01	0.00	0.01	0.01	0.03	0.08	0.12	0.13	0.09	0.06	0.08	0.10	0.10	0.07	0.06	0.09	0.15	0.21	0.18	0.13	0.10	0.03
Leak	0.27	0.19	0.17	0.16	0.16	0.17	0.22	0.31	0.42	0.24	0.23	0.31	0.24	0.41	0.24	0.56	0.32	0.26	0.26	0.32	0.29	0.36	0.24	1.19

Time (0:00 hours)

Fig. 3. AD diurnal demand pattern for households with a less than (<) three star rating.

Other disaggreted consumption patterns

2. The average daily diurnal demand pattern for households with greater or equal to (>=) three start rating;

3. AD diurnal demand pattern for 50 most efficient households;

4. AD diurnal demand pattern for 50 least efficient households.

Daily consumption pattern of clustered households

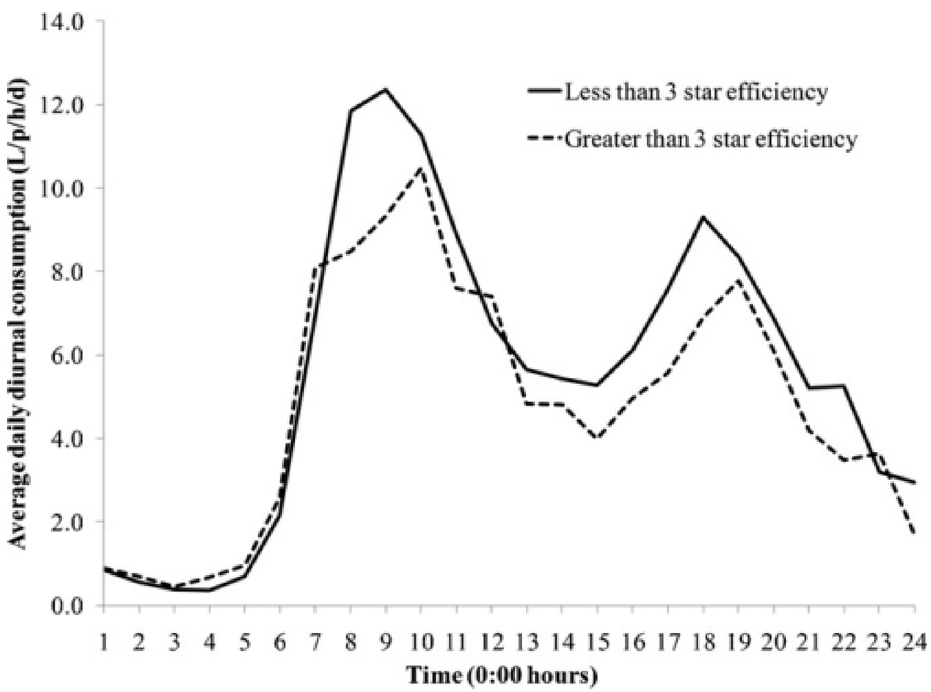


Fig. 7. AD diurnal demand pattern comparison for household clusters of greater than or equal to (≥) and less than (<) a three star rating.

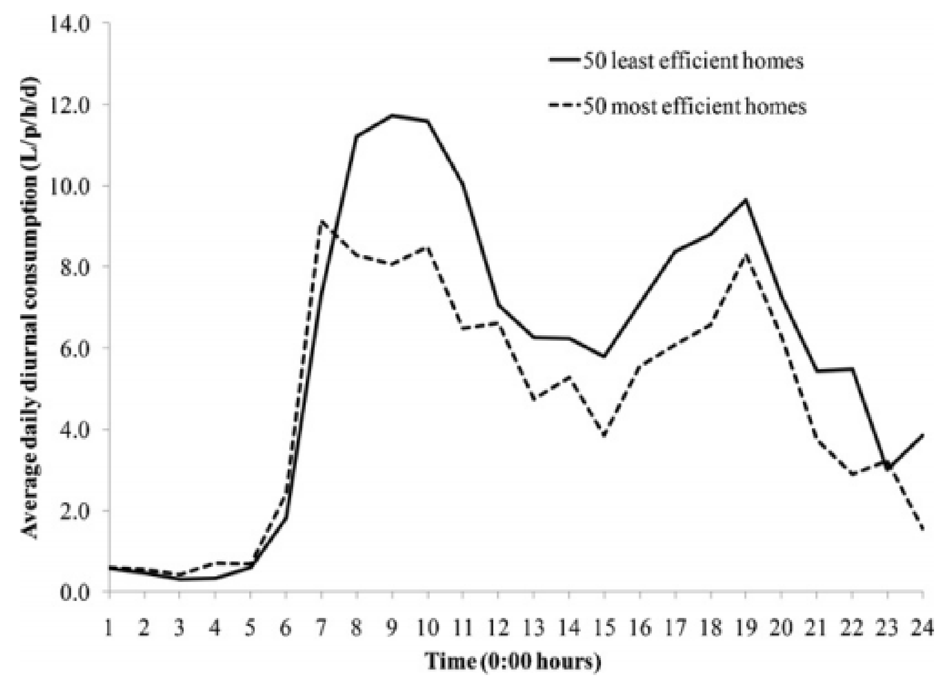


Fig. 8. AD diurnal demand pattern comparison of 50 least and most efficient households.

Morning and afternoon peak of the clustered households

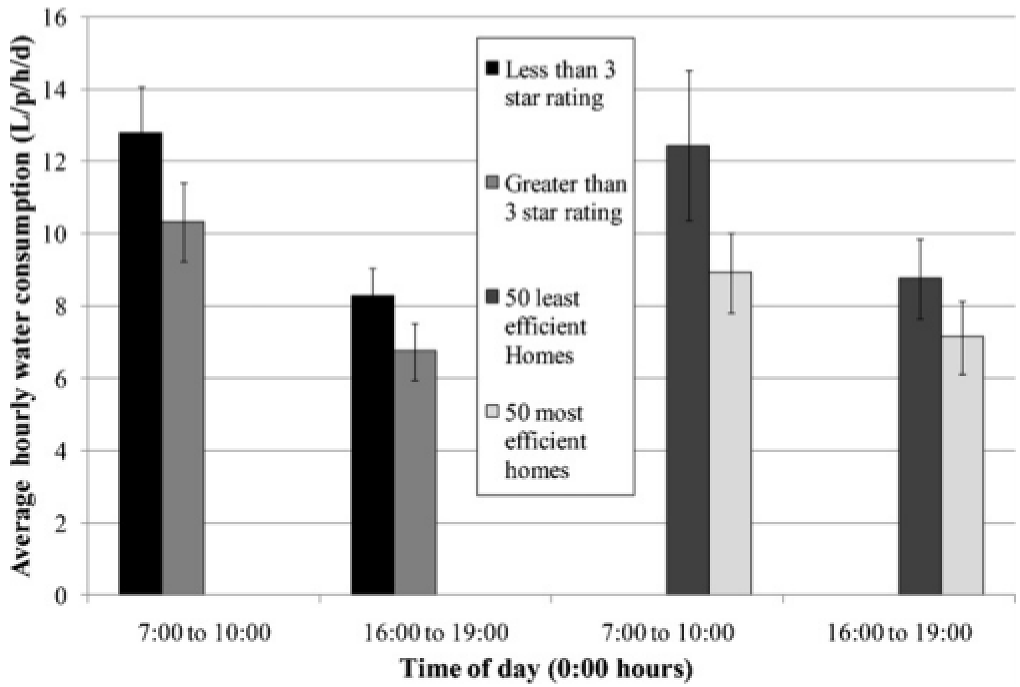


Fig. 9. Efficiency cluster comparison for peak morning and afternoon periods.

Key Conclusions

- Statistically significant reduction in AD peak hour water consumption in households with a higher composite star rating
- More efficient water appliances decreased peak demand in the diurnal consumption patterns.

Paper 2: Smart meter enabled disaggregation of urban peak water demand: precursor to effective urban water planning (By Graham et. al., 2012)

- Research objectives
  - Identify the proporation of indoor and outdoor residential water consumption
  - Identify the major courses of significant consumption fluctuation (e.g.. temperature, lot size, dwelling types, etc.)
  - Measure the end use volumnes at peak demand period
- Data sets
  - 2884 residential and light commercial customers (houly resolution within one year).
    - 4 groups: 1 urban residential, 1 suburban residential, 1 mixed residential and commercial, 1 commercial.
    - 2494 single residential, 390 multi-residential

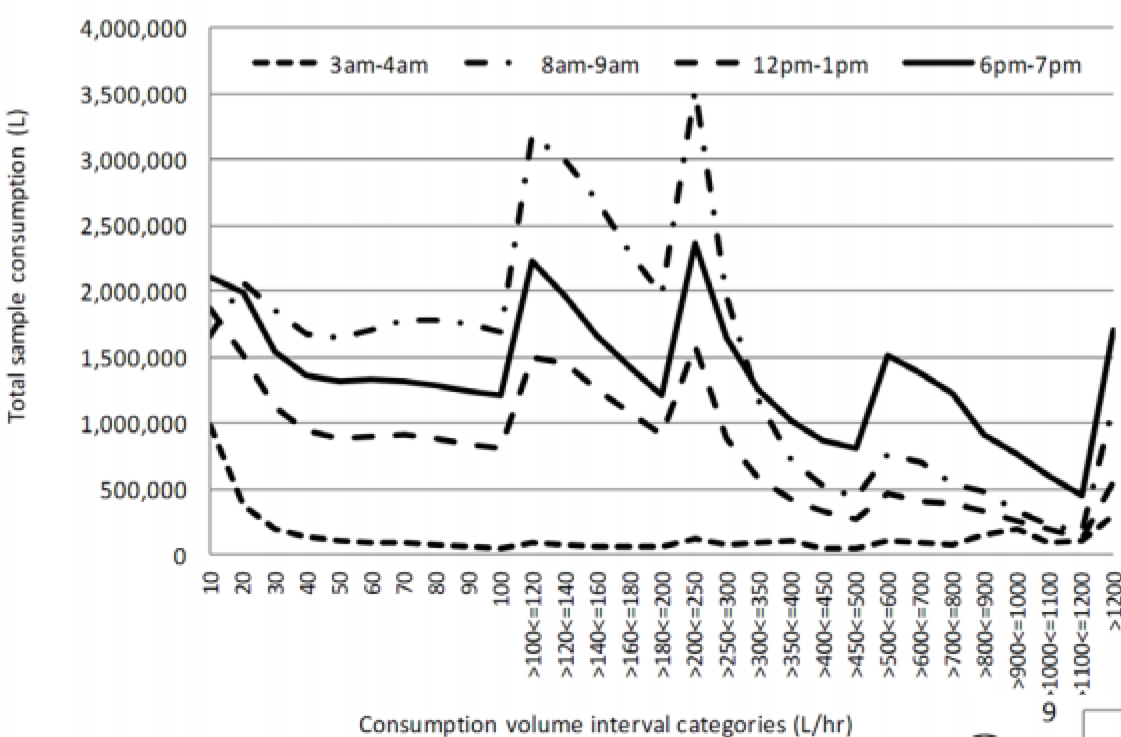
Identify the volume ranges for typical water use types

Table 36. Typical water use types for various volume ranges

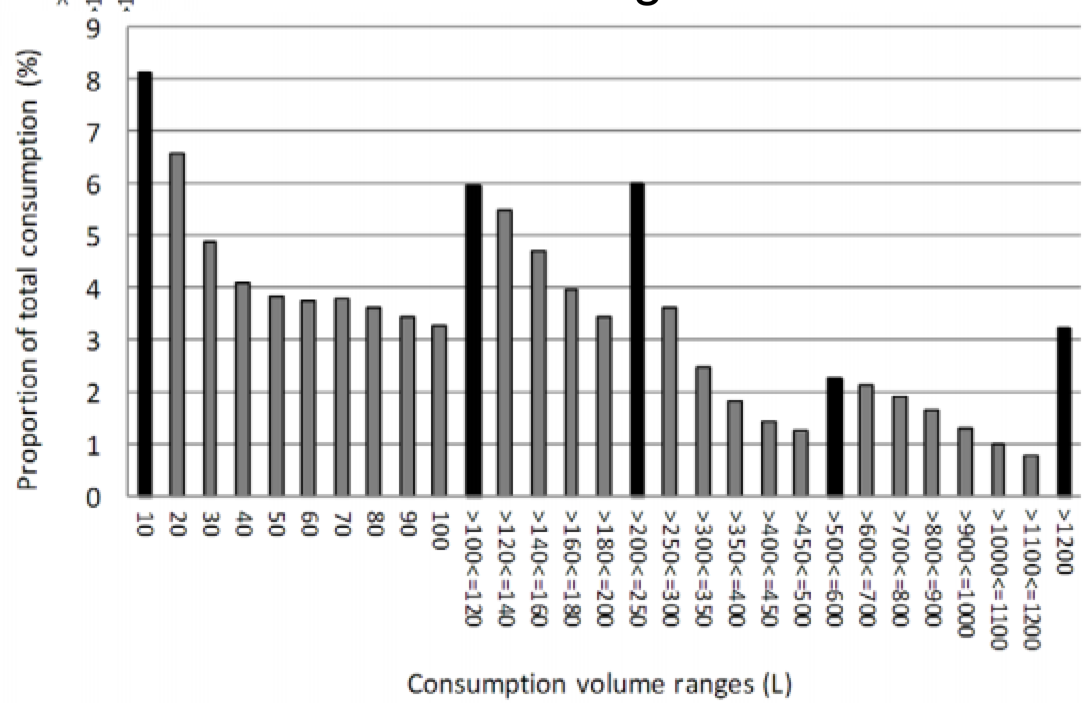
Typical uses for water at various volumes per hour			
10[†]-100 L	>100<=300 L	>300<=600 L	>600 L
Toilet flush[‡]	Multiple use and/or combinations of types	Outdoor use	Outdoor use
Personal hygiene (washing hands etc)	Toilet flush	Multiple use and/or combinations of types	Multiple use and/or combinations of types
Cooking/drinking	Personal hygiene (washing hands etc)	Washing machine	Washing machine
Shower/bath	Cooking/drinking	Dishwashing	Dishwashing
Dishwashing	Shower/bath	Shower/bath	Shower/bath
Multiple use and/or combinations of types	Dishwashing	Cooking/drinking	Cooking/drinking
Washing machine	Washing machine	Toilet flush	Toilet flush
Outdoor use	Outdoor use	Personal hygiene (washing hands etc)	Personal hygiene (washing hands etc)
All the above	All the above	All the above	All the above

†10L per hour minimum resolution of meter; ‡ranked in order of likelihood in water use range.

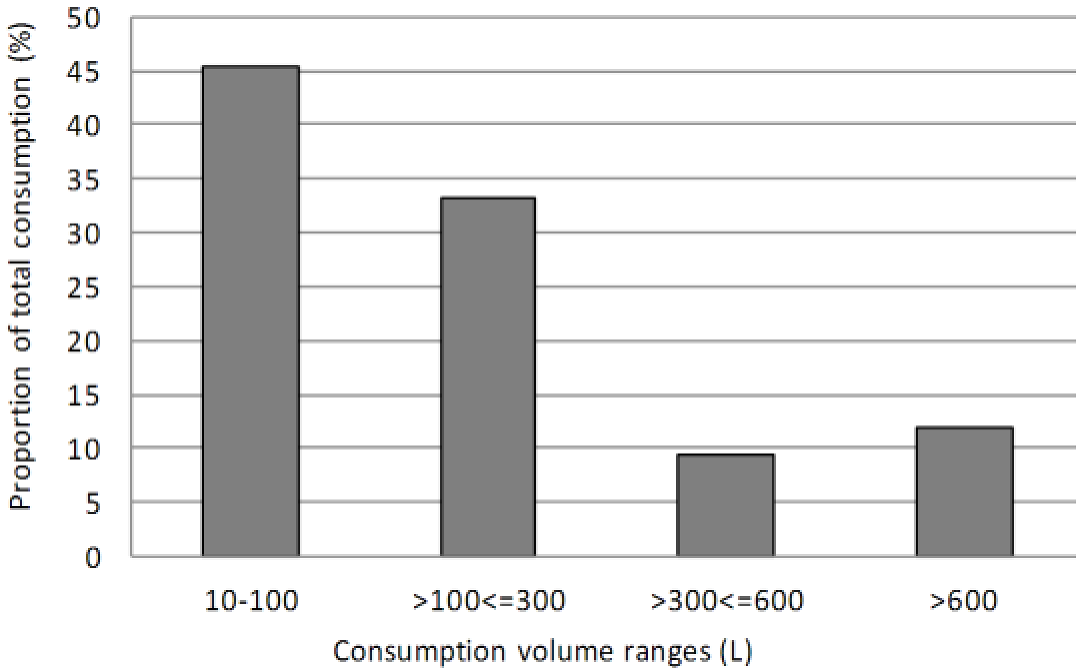
The breakdown by volumn range of average hourly consumption in for selected period



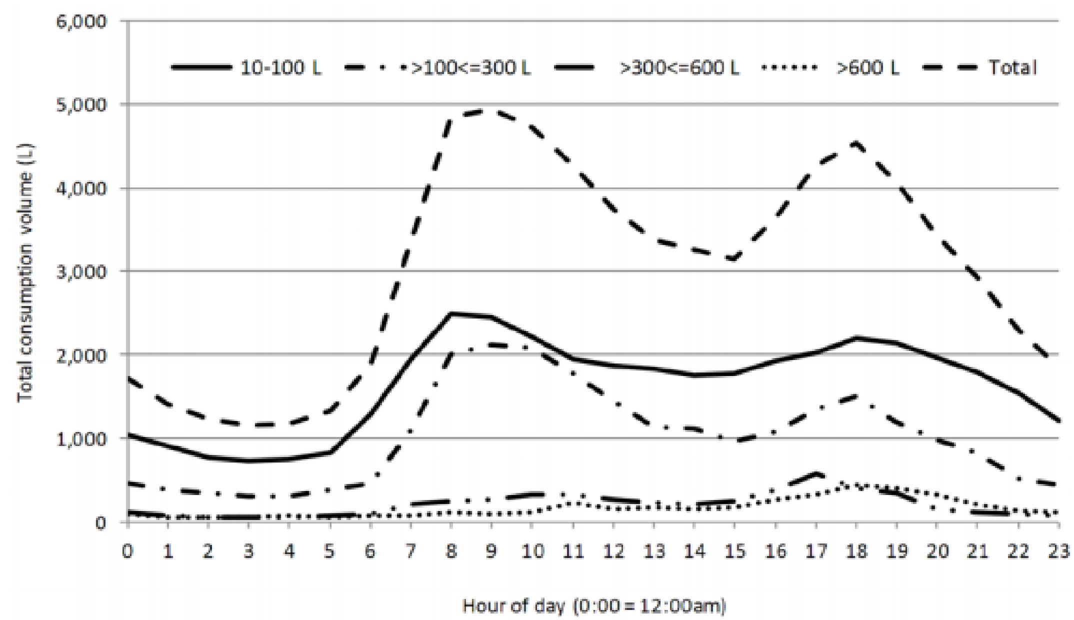
Proportion of total consumption in each volume range



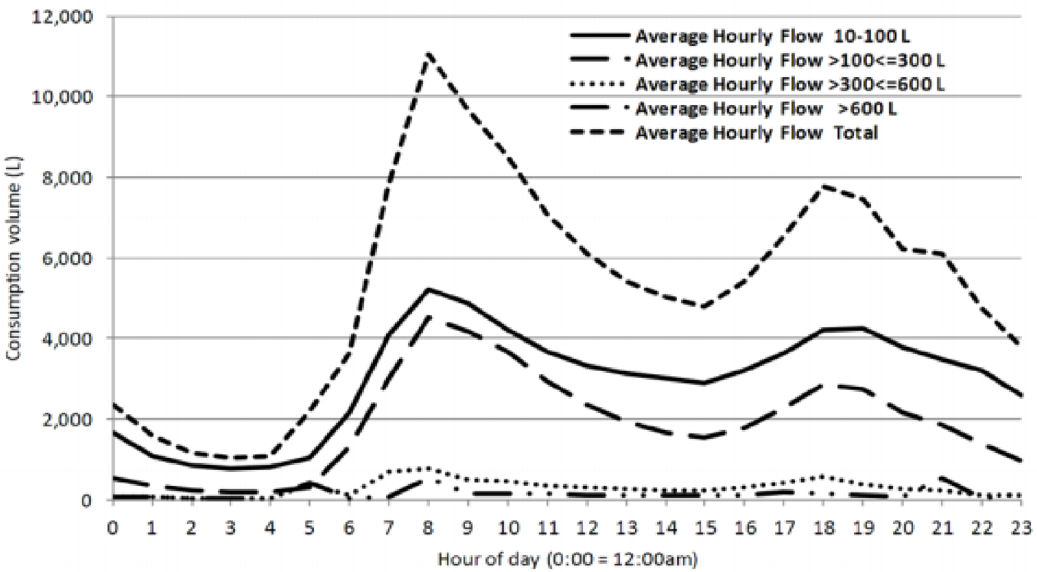
Proportion of consumption in four volume ranges as % of total consumption



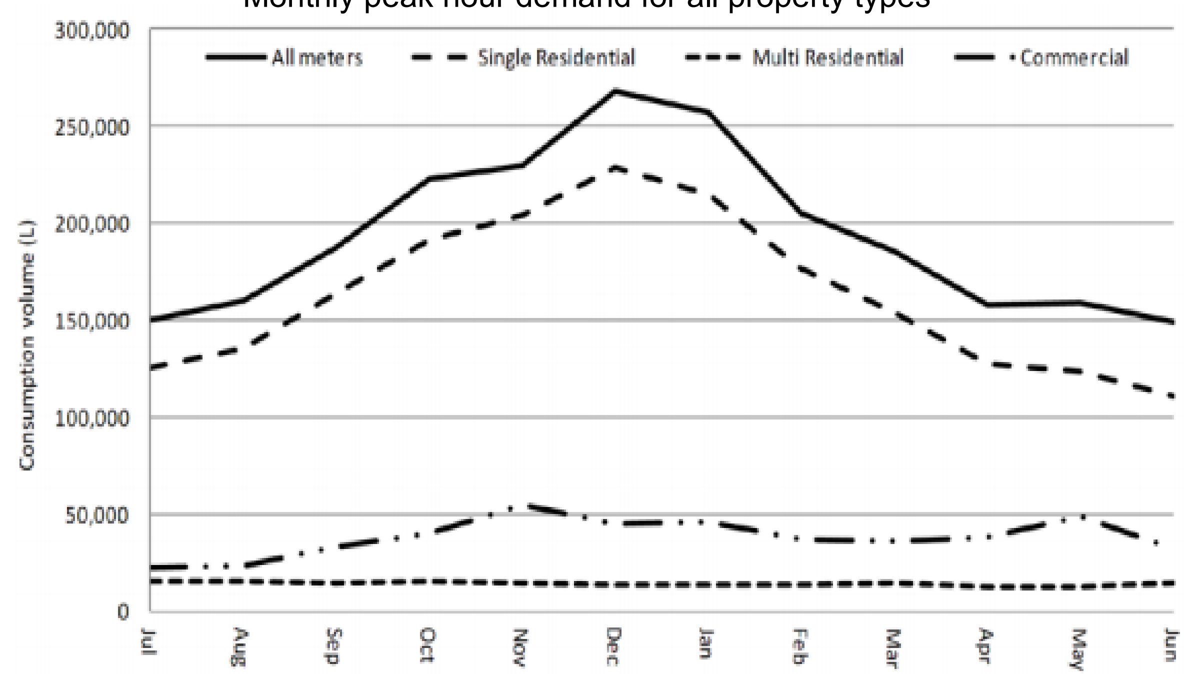
Average hourly consumption for four volume ranges



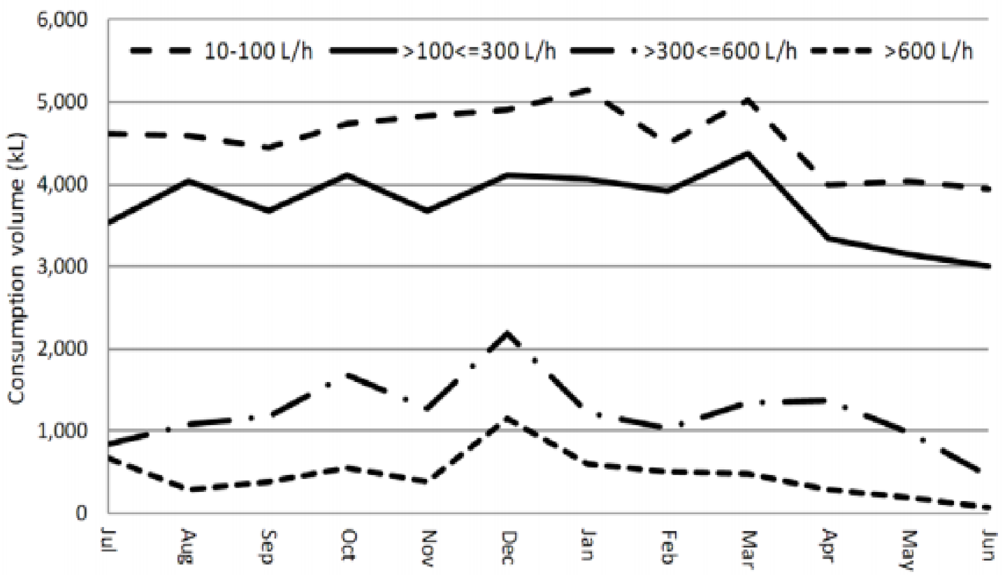
Multi-residential average hourly consumption for four volume ranges



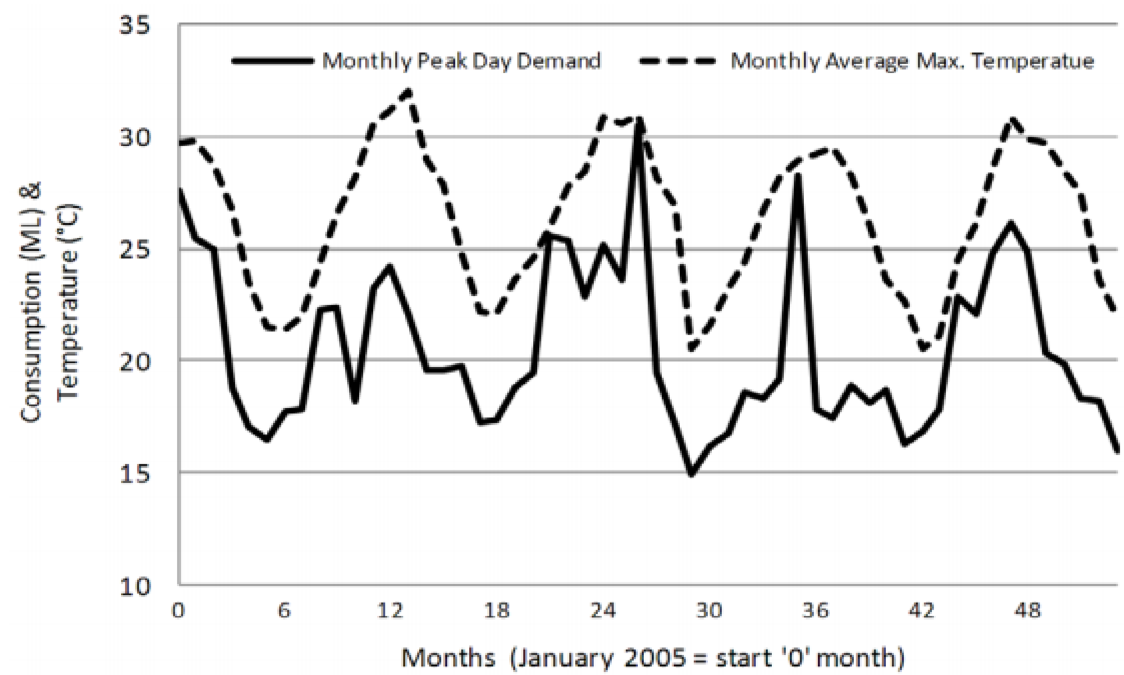
Monthly peak hour demand for all property types



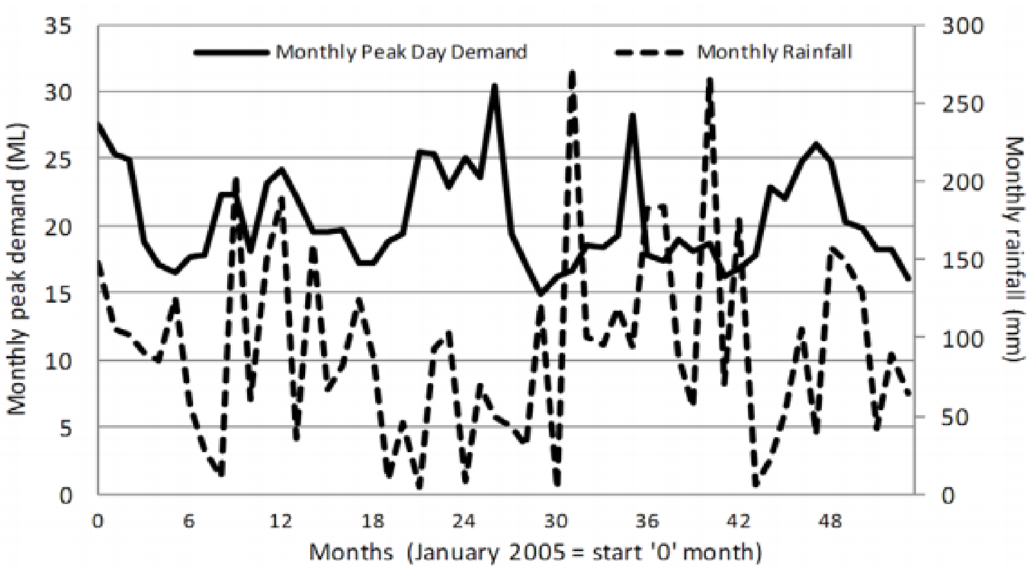
Monthly consumption in four volume ranges



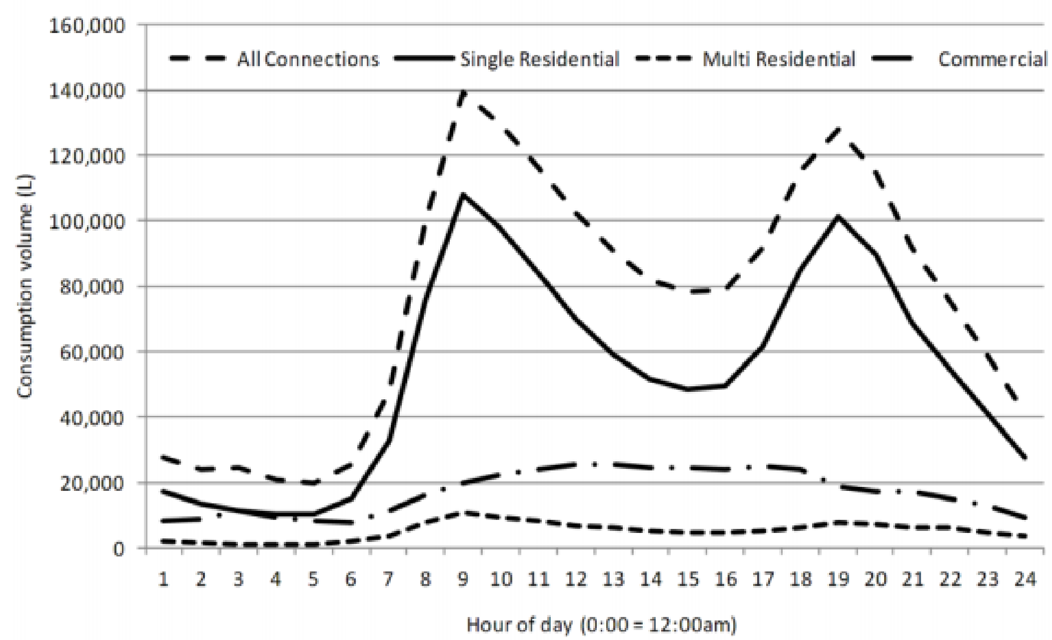
Monthly peak water demand and monthly average max temperature



Monthly peak demand and monthly average monthly rainfall



Comparison of diurnal pattern by property type



Paper 3: Water demand pattern classification from smart meter data (By McKenna, et. Al, IBM research)

- Objectives:
  - Develop an approach for classfication of demand patterns
  -

  Data sets:
  - Hourly readings of 6-month period at a single district metered area
  - Commercial and residential customers
  - Only weekday data is used

Demand pattern discovery

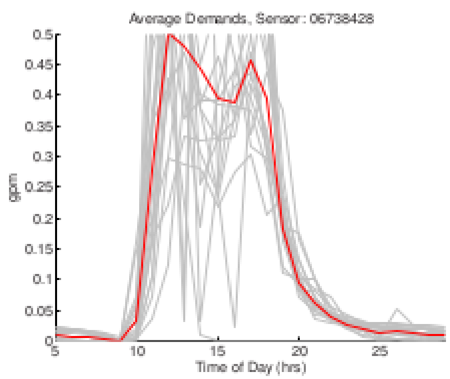
- Method:
  - Use Gaussian Mixture Models (GMM) for representing the demand pattern:

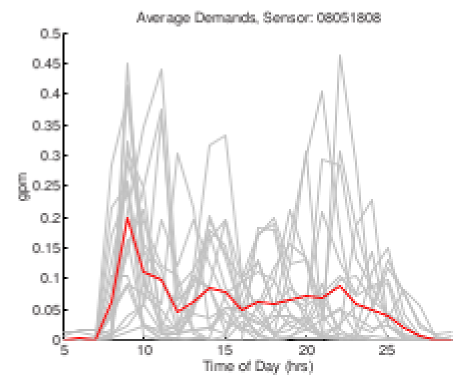
$$p(\chi|\Theta) = \prod_{i=1}^{N} p(x_i|\Theta) = \mathcal{L}(\Theta|\chi) \quad \text{where} \quad p(x|\Theta) = \sum_{i=1}^{M} \alpha_i p_i(x|\theta_i)$$

  - Use Multivariate clustering using k-means algorithm:

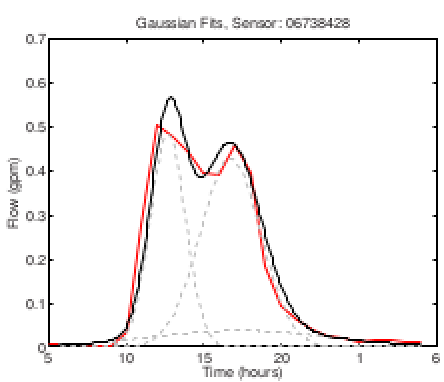
$$J_s(\Gamma, A) = \sum_{i=1}^{K} \sum_{j=1}^{N} \gamma_{ij} \| x_j - a_i \|^2$$

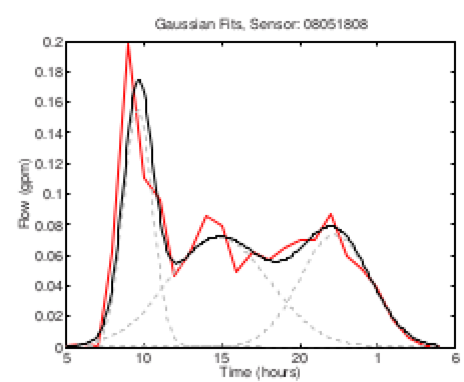
Use GMM to fit daily demand pattern





Individual daily demands for 20 weekdays (grey) and the average demand (red) are shown for three different sensors





Gaussian Mixture Model fits to average demands for three sensors.

Four clusters and their three-component GMM's for the January 2011 weekday data.

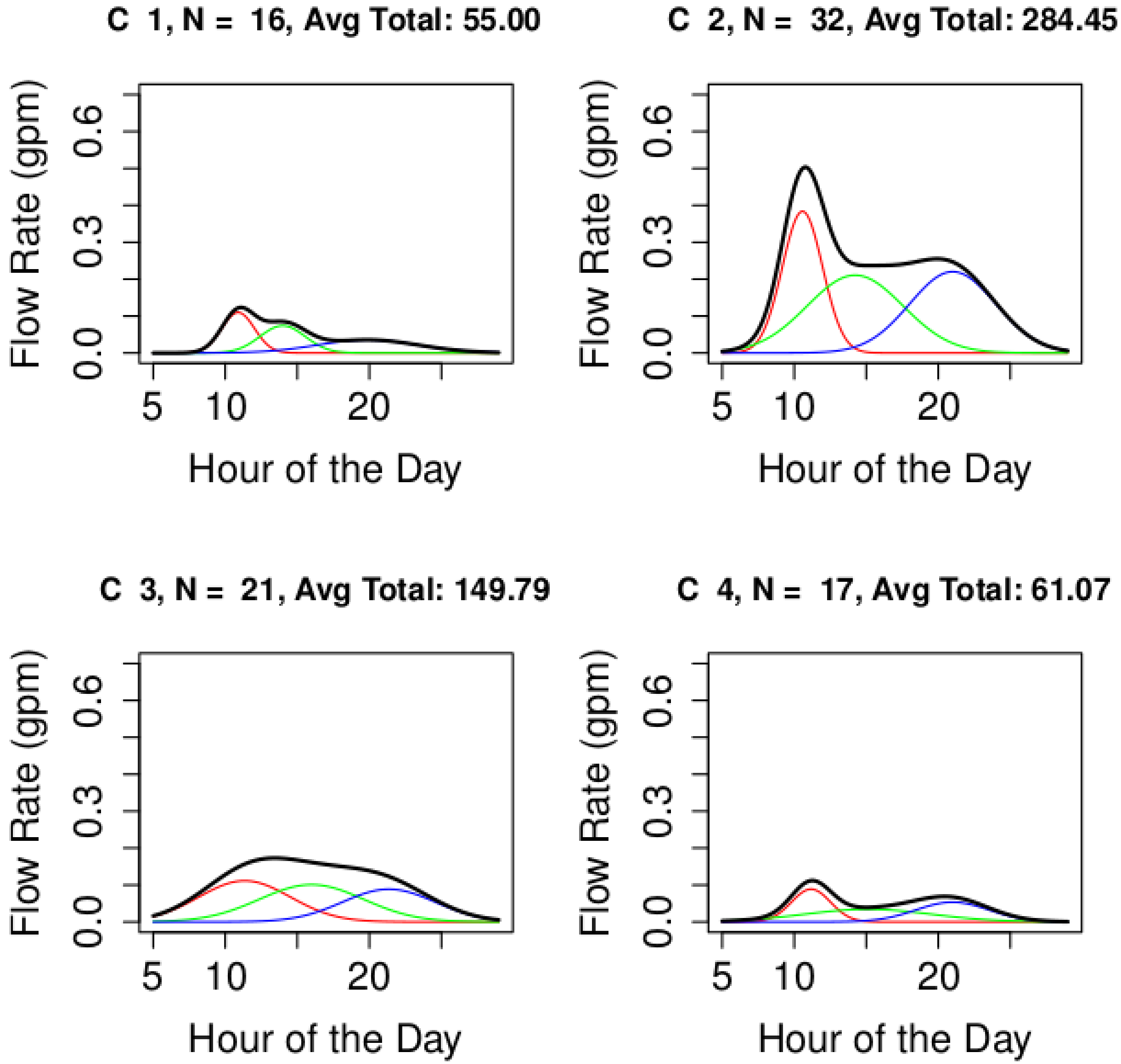


Fig. 5: Four clusters and their three-component GMM's for the January 2011 weekday data.

Paper 4: A class of time-series urban water demand models with nonlinear climatic effects (*by shaw, University of Tennessee*)

- Water demand model:
  - Model water consumption into *Base Use* + Seasonal Use.
  - Season Use consists of three components: a potential use (dependent on temperature only), a water use reduction (due to rainfall) and a random component

Urban water demand Model

- Base Use: $$B_m = \beta_0 + \beta_1 H_\tau(T_m) + \beta_2 G_\gamma(R_m) + \sum_i \beta_{i+2} X_{i,m} + \nu_m \qquad \forall\ m \in \ \textit{winter months}$$
  - $$H_\tau(T_m) = \begin{cases} T_m - \tau & (T_m \geq \tau) \\ 0 & \textit{otherwise} \end{cases} \qquad G_\gamma(R_m) = \begin{cases} R_m & (R_m \leq \gamma) \\ \gamma & \textit{otherwise} \end{cases}$$
  - Tm is the monthly maximum aire temperature
  - R monthly total rainfall
  - X a set of socioeconomic variable
  - T, and r are the thresholds of temperature, and rainfall
  - Use the lowest level monthly use, e.g., Dec.~ Feb.
- Seasonal Use:
  - The seasonal use in Winter: the total use is substracted the base use.
  - The seasonal use in Summer: $$S_m = \beta_0 + \beta_1 m + \beta_2 T_m + \beta_3 R_m + u_m \qquad (17)$$ $$\forall\ m \in \text{(April–October)}$$

    M1: use multiple linear regression model

    M2: Non-linear models with rainfall thresholds , e,g.,

$$S_m = (1 + \text{RainEff})(\beta_0 + \beta_1 m + \beta_2 T_m) + u_m \qquad (18)$$

$$\forall\ m \in \text{(April–October)}$$