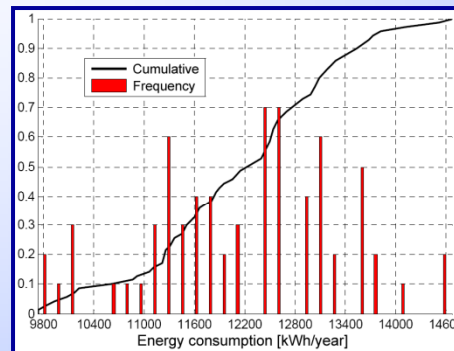




# Influence of Occupants' Behaviour on the Energy Consumption of Domestic Buildings

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# Introduction

- ◆ Assessment of energy reduction initiatives, annual cost, life cycle cost, emission impact, etc. requires reasonably accurate energy consumption calculations
- ◆ Several investigations reveal significant uncertainties in the determination of building energy consumption (deviation may exceed 100% in extreme cases)
- ◆ Occupants' behaviour is reported to contribute substantially to the variance
- ◆ A number of similar Danish domestic buildings are investigated to determine uncertainty and indentify important sources of variance
- ◆ A theoretical and empirical study of the influence of occupants' behaviour on the energy consumption are undertaken



# Building Description

## 8 almost similar red-bricked semi-detached houses

- Located in western part of Denmark
- Conditioned area 149 m<sup>2</sup>
- Room height 2.37 m, 0.35 m cavity walls
- Naturally ventilated
- Heated by district heating







# Building Description, 2

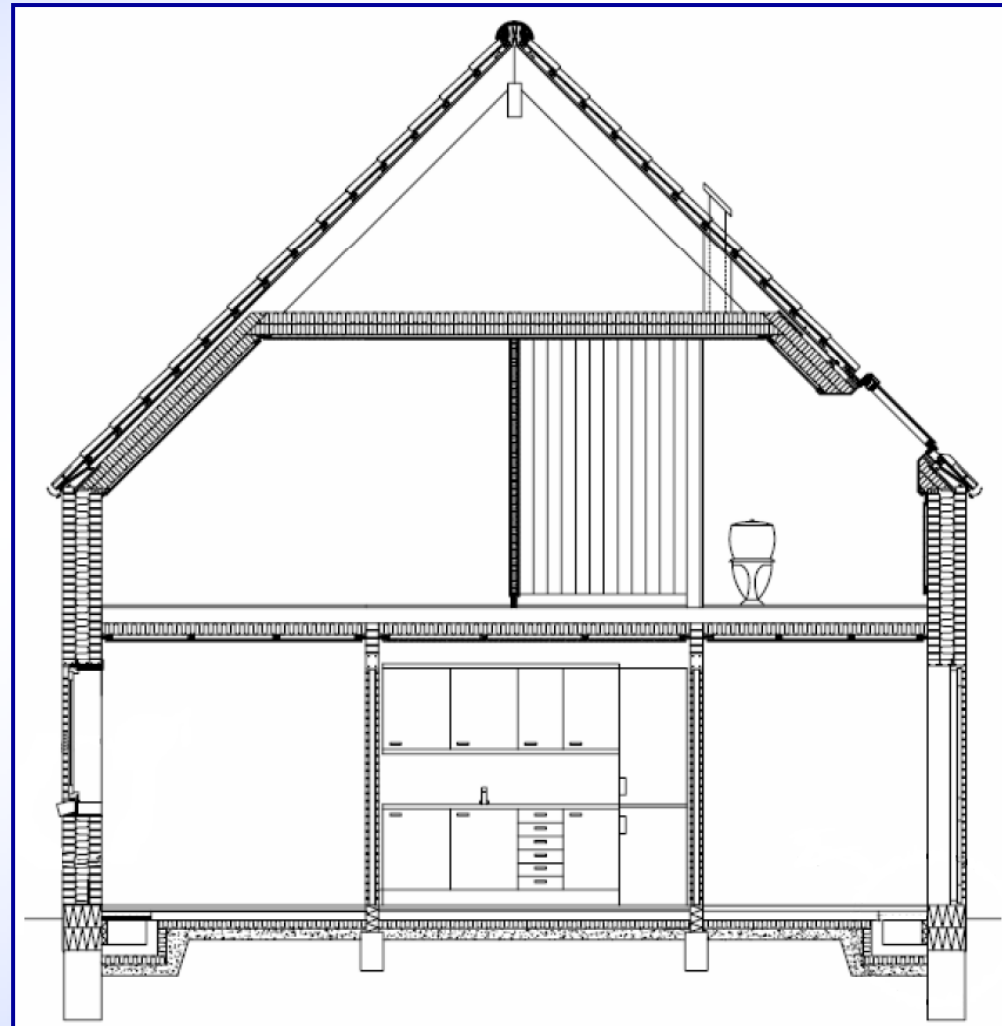
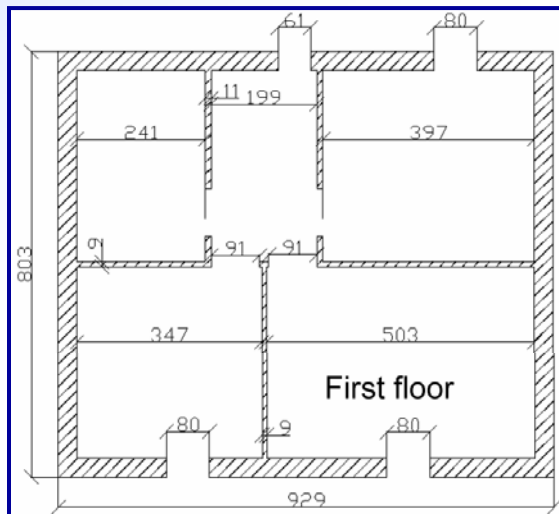
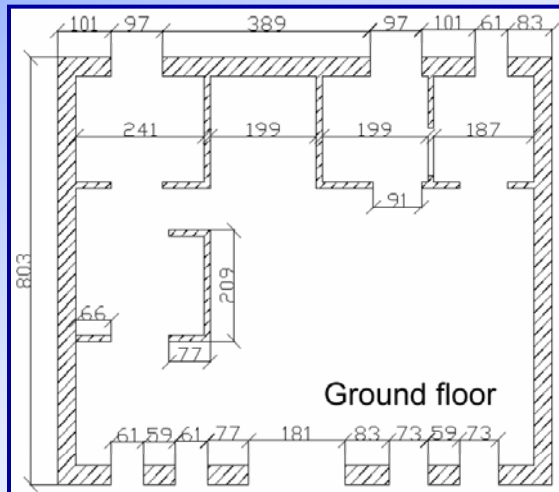
## Example of buildings and surroundings





# Building Description, 3

## Horizontal plan and sectional view





# Measurements

- Blower door (building leakage @ 50 Pa)
- Tracer gas (leakage distribution and air infiltration)
- Internal temperature (thermal comfort and preferences)
- Weather data: local external temperature, local meteo data (wind speed, wind direction, temperature, rel. humidity, atm. pressure, cloud cover, global solar rad.)
- Questionnaire (occupant number, age, occupied period, bathing habits, use of computers, TV, appliances, etc.)
- District heating, water, electricity (reading of meters)





# Measurement Results

**8 buildings,  $\mu$  is mean value and  $\sigma$  is standard deviation (2005 is a “typical” year)**

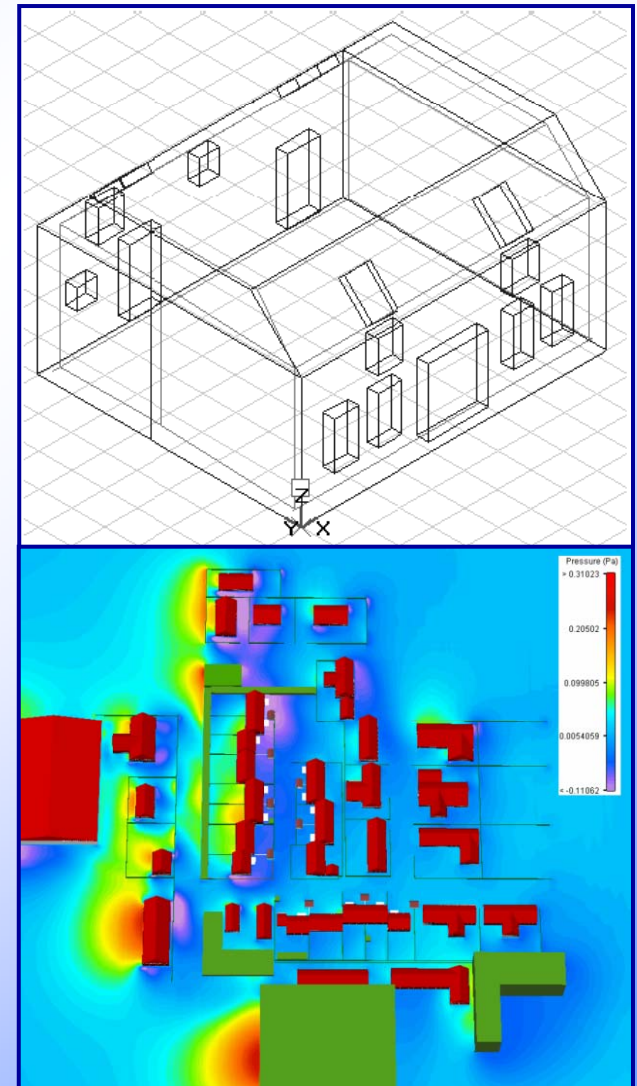
Measurement	Unit	$\mu$	$\sigma$
Infiltration (leakage)	l/(s·m <sup>2</sup> ) @ 50Pa	3.00	0.23
Internal air temperature set-point	°C	22.19	1.03
Internal heat load, appliances	W/m <sup>2</sup> (time average)	2.93	1.21
Internal heat load, occupants	W/m <sup>2</sup> (time average)	1.11	0.56
Airing, number	Airings per day	1.21	0.50
Airing, duration	Minutes per airing	10.88	8.72
2005 external air temperature	°C	9.3	7.6
2005 wind speed	m/s	4.6	2.5
2005 total water consumption	m <sup>3</sup> /year	125.3	41.2
2005 electricity consumption	kWh/(m <sup>2</sup> ·year) (kWh/year)	27.3 (4,079)	11.4 (1,697)
2005 district heating consumption	kWh/( m <sup>2</sup> ·year) (kWh/year)	73.0 (10,886)	16.6 (2,480)





# Building Model

- Hygrothermal building simulation programme *BSim* applied for the simulations
- CFD (*Flovent*) and MZM (*Comis*) used to improve description of natural ventilation and air infiltration
- Danish DRY applied as weather data (compared with local meteo station data)
- 13 stochastic input parameters (distributions) for screening SA
- Reduced set applied for quantitative analyses (SA and UA)

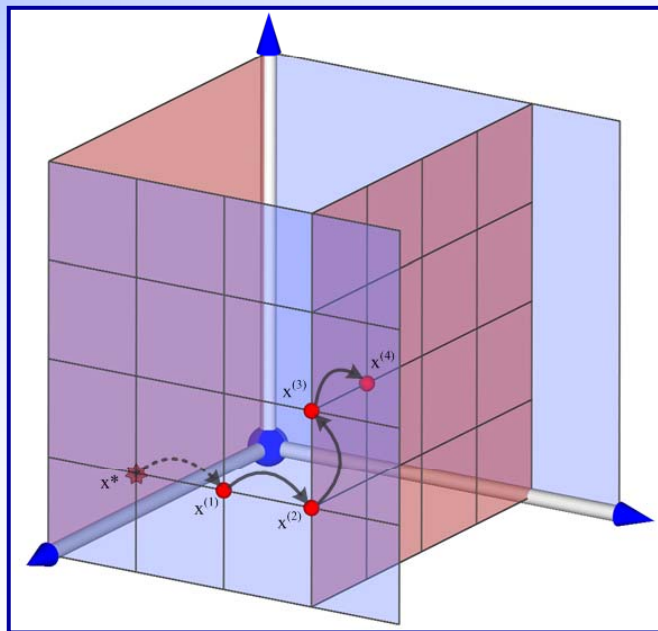




# Screening Sensitivity Analysis

## Method of Elementary Effects (Morris Method)

$$EE(x_1, \dots, x_k) = \frac{y(x_1, x_2, \dots, x_{i-1}, x_i + \Delta, x_{i+1}, \dots, x_k) - y(x_1, \dots, x_k)}{\Delta}$$



- OAT (one factor at a time)
- Baseline changes at each step wanders in the input factors space
- Estimate the main effect of a factor by computing  $r$  numbers of local measures at  $\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_r$  in the input space

$$\mu = \sum_{i=1}^r |EE_i| / r$$

$$\sigma = \sqrt{\sum_{i=1}^r (EE_i - \mu)^2 / r}$$



# Screening SA Input Parameters

- **13 stochastic input parameters (distributions)**
- **Normal, Lognormal and Discrete distributions applied**
- **No correlation assumed**

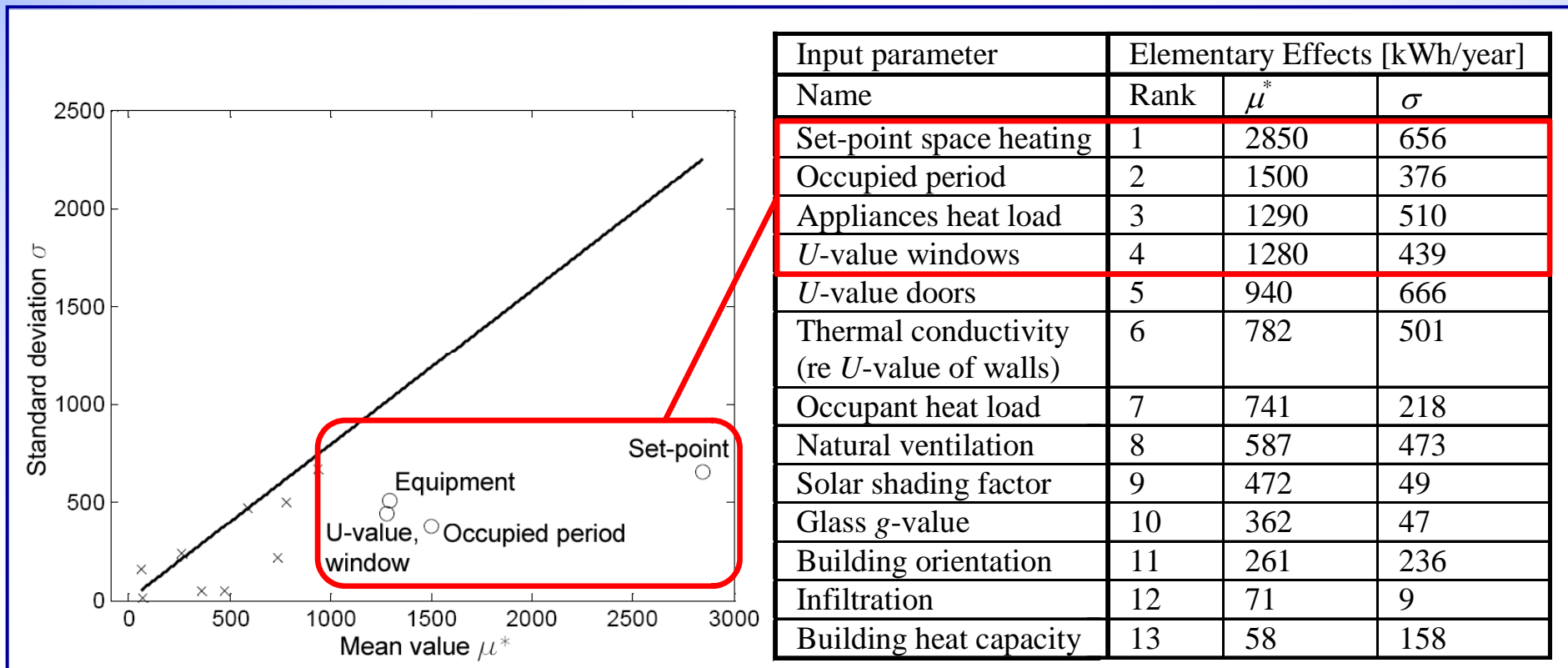


Input parameter		Distribution		EE [kWh/year]		
Name	Unit	Type	Interval; $\mu$ ; $\sigma$	Rank	$\mu^*$	$\sigma$
<b>Wholly occupant behaviour related parameters:</b>						
Set-point space heating	°C	N	21 - 24; 22; 0.71	1	2850	656
Occupied period	h/day	D	10 – 18	2	1500	376
Appliances heat load	W	N	215 – 730; 437; 100	3	1290	510
Occupant heat load	Occ. No.	N	0.522 – 2.861; 1.594; 0.5	7	741	218
<b>Partly occupant behaviour related parameters:</b>						
Natural ventilation	m <sup>3</sup> /s	N	0.0386 – 0.0433; 0.041; 0.001	8	587	473
Solar shading factor	-	N	0.5 – 1.0; 0.8; 0.1	9	472	49
<b>Building related parameters:</b>						
<i>U</i> -value windows	W/m <sup>2</sup> K	N	1.1 – 2.9; 2.4; 0.4	4	1280	439
<i>U</i> -value doors	W/m <sup>2</sup> K	N	2.2 – 3.3; 2.9; 0.2	5	940	666
<i>U</i> -value walls (optimal value increase)	%	L	0 - 40; 2.5; 0.7 (0.267 – 0.376 W/m <sup>2</sup> K)	6	782	501
Glass <i>g</i> -value	-	N	0.59 – 0.76; 0.67; 0.04	10	362	47
Building orientation	°	D	21 – 291	11	261	236
Infiltration	l/(s·m <sup>2</sup> )	N	0.20 – 0.24; 0.215; 0.008	12	71	9
Building heat capacity	Wh/m <sup>2</sup> K	N	120 - 144; 132; 4	13	58	158



# Results from Screening SA

- Screening by the method of Elementary Effects
- 140 parameter combinations
- Four most important parameters marked as circles







# Detailed SA and UA Input

- Most important parameters selected
- Normal and Exponential distributions applied
- No correlation assumed

Input parameter		Distribution	
Name	Unit	Type	Interval; $\mu$ ; $\sigma$ or $d$
Set-point space heating	°C	N	20 - 25; 22.27; 0.75
<i>Infiltration / Nat. vent.</i>			
Basic air change rate, $n_0$	1/h	N	1.0 - 1.2; 1.1; 0.033
Temperature exponent, $t_p$	-	N	0.5 - 0.6; 0.55; 0.017
Wind factor, $c_v$	s/(h·m)	N	0.034 - 0.064; 0.058; 0.007
Occupied period	h/day	N	12 - 18; 14.9; 0.95
Occupant heat load	W/m <sup>2</sup> (Occupants)	E	0.68 - 6.00; 1.10; 0.68 (1.01 - 8.95; 1.64; 1.01)
Appliances heat load	W/m <sup>2</sup> (kW)	E	1.62 - 6.00; 0.70; 1.62 (0.24 - 0.90; 0.10; 0.24)



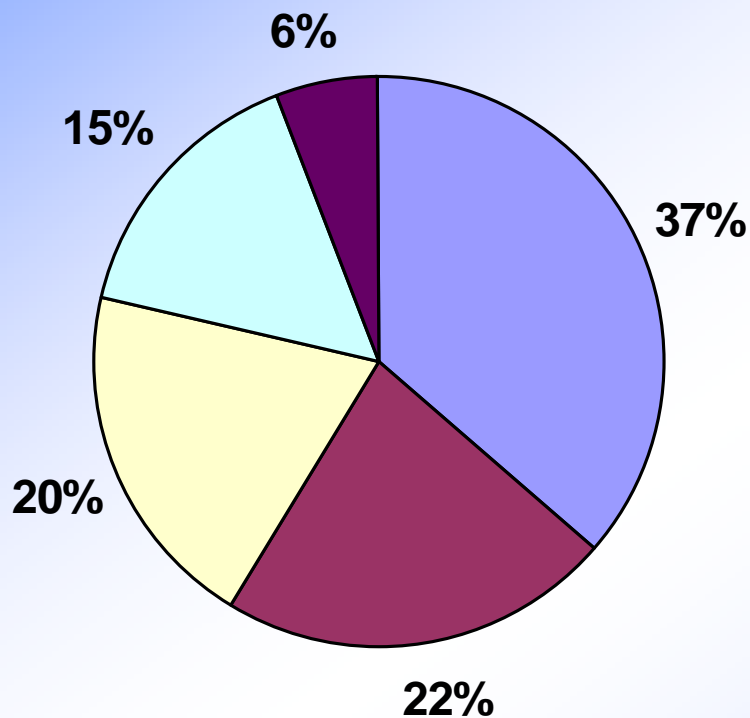
# Results from Quantitative SA

- SPEA = Spearman coefficient
- PEAR = Pearson product moment correlation coefficient
- SRC = Standardised Regression Coefficient
- SRRC = Standardised Rank Regression Coefficient

Input parameter	SPEA		PEAR		SRC		SRRC	
	%	Rank	%	Rank	%	Rank	%	Rank
Set-point space heating	36.9	1	38.0	1	34.7	1	41.1	1
Occupant heat load	22.6	2	22.8	2	25.5	2	22.1	2
Appliances heat load	15.7	3	20.7	3	15.6	4	19.3	3
Basic air change rate, $n_0$	14.6	4	4.7	5	16.0	3	6.2	5
Occupied period	5.9	5	6.8	4	5.6	5	7.7	4
Temperature exponent, $t_p$	2.4	6	3.0	7	0.3	7	0.8	7
Wind factor, $c_v$	2.0	7	3.9	6	2.4	6	2.9	6



# Results from Quantitative SA, 2



- Set-point space heating
- Occupant heat load
- Natural ventilation and infiltration
- Appliances heat load
- Occupied period

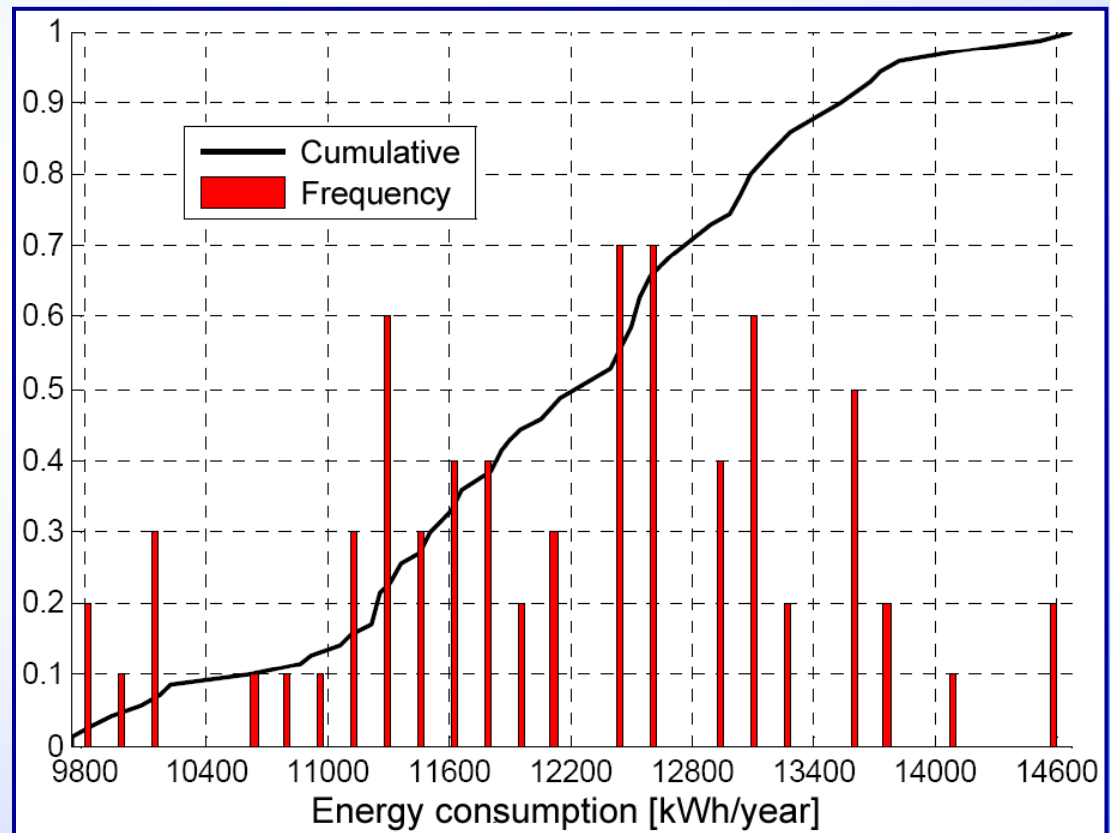


# Results from Uncertainty Analysis

- Frequency and CDF shown in figure
- Based on 70 realisations (Monte Carlo analysis)
- Latin Hypercube sampling
- **Mean 12,008 kWh/year**
- Median 11,925 kWh/year
- Std.dev. 1,294 kWh/year
- **Coef. of variation 0.11**
- Skewness 0.025
- Kurtosis 2.269

## Measurements (2005)

- Mean 10,886 kWh/year
- Coef. of variation 0.23





# Conclusions

- ◆ A theoretical and empirical study of the influence of occupants' behaviour on energy consumption of domestic buildings are undertaken
- ◆ Calculated energy consumption of 8 almost identical domestic buildings in Denmark is compared with measured energy consumption
- ◆ Uncertainty and sensitivity are determined by stochastic modelling based on input distributions and Monte Carlo simulation
- ◆ Reasonable agreement between measurement and simulation, however, significant differences may occur (coef. of variation approx. 0.1 – 0.2)
- ◆ The most important (sensitive) parameters are related to occupants' behaviour.
- ◆ The influence of occupants' behaviour is not well understood. More research should be undertaken to improve understanding and proper assessment of total building energy consumption