ECE 333 – GREEN ELECTRIC ENERGY

9. Basic Concepts in Power System Economics

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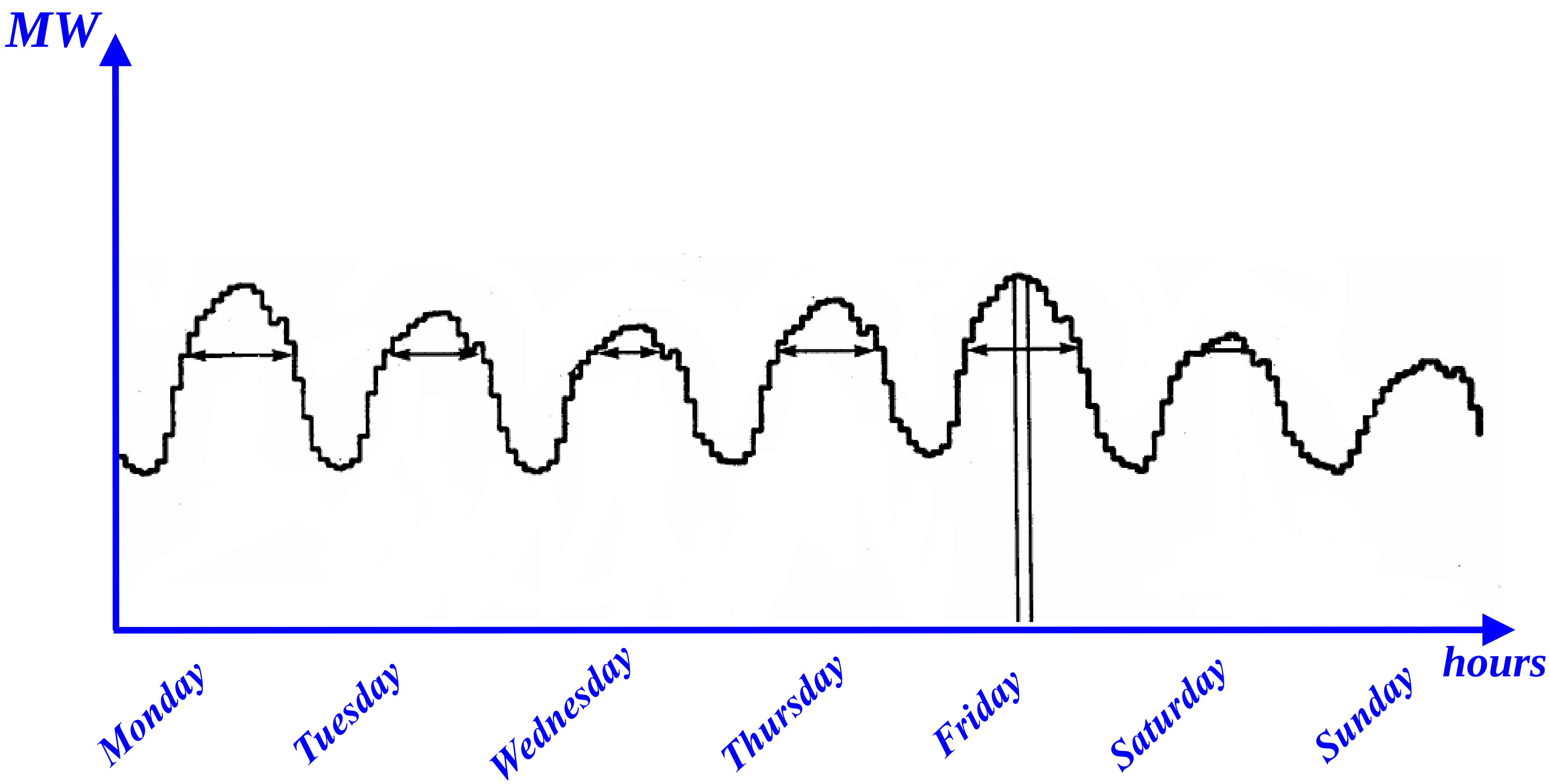
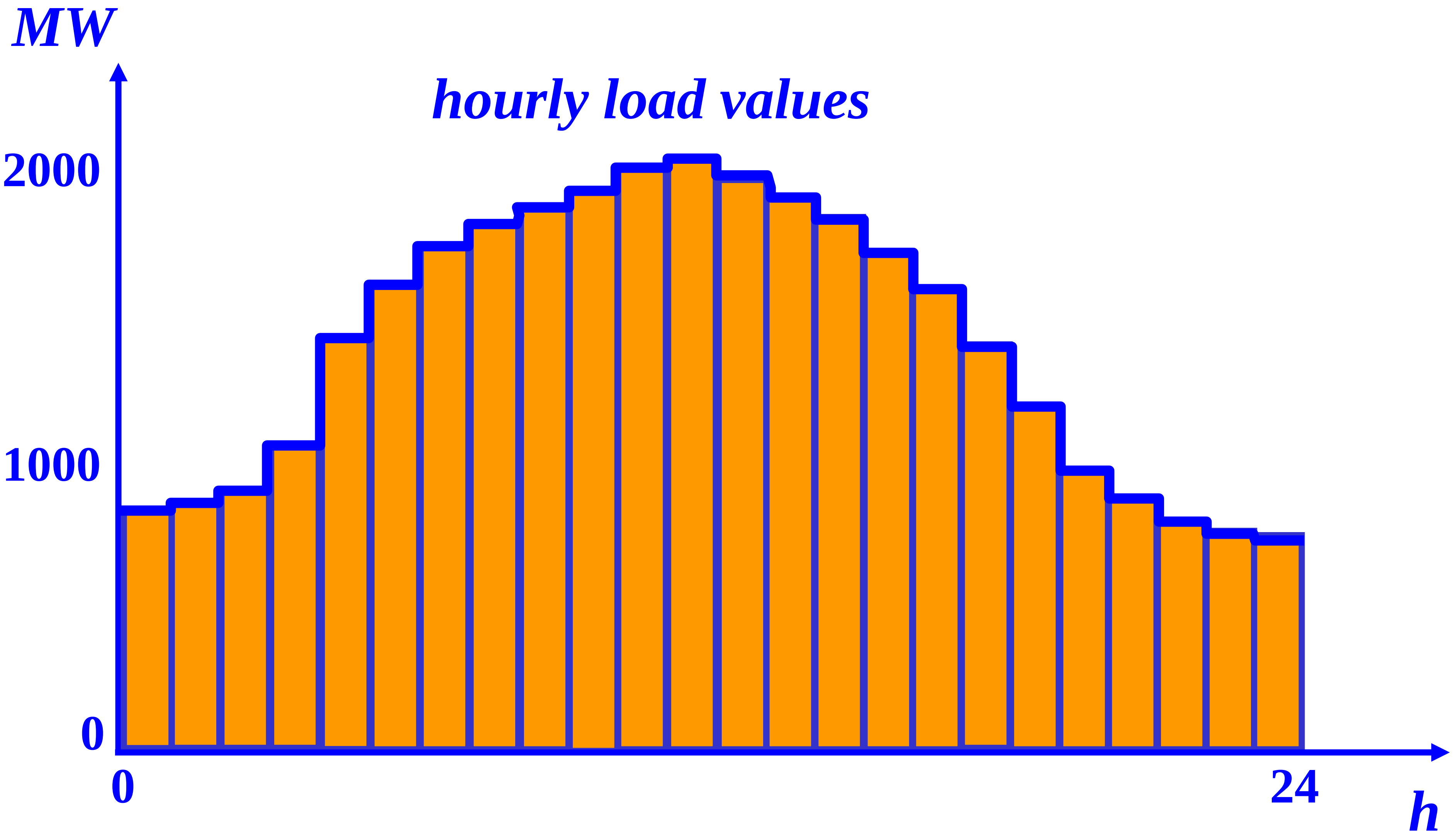
CHRONOLOGICAL LOAD FOR A SUMMER WEEK



A WEEKDAY CHRONOLOGICAL LOAD CURVE

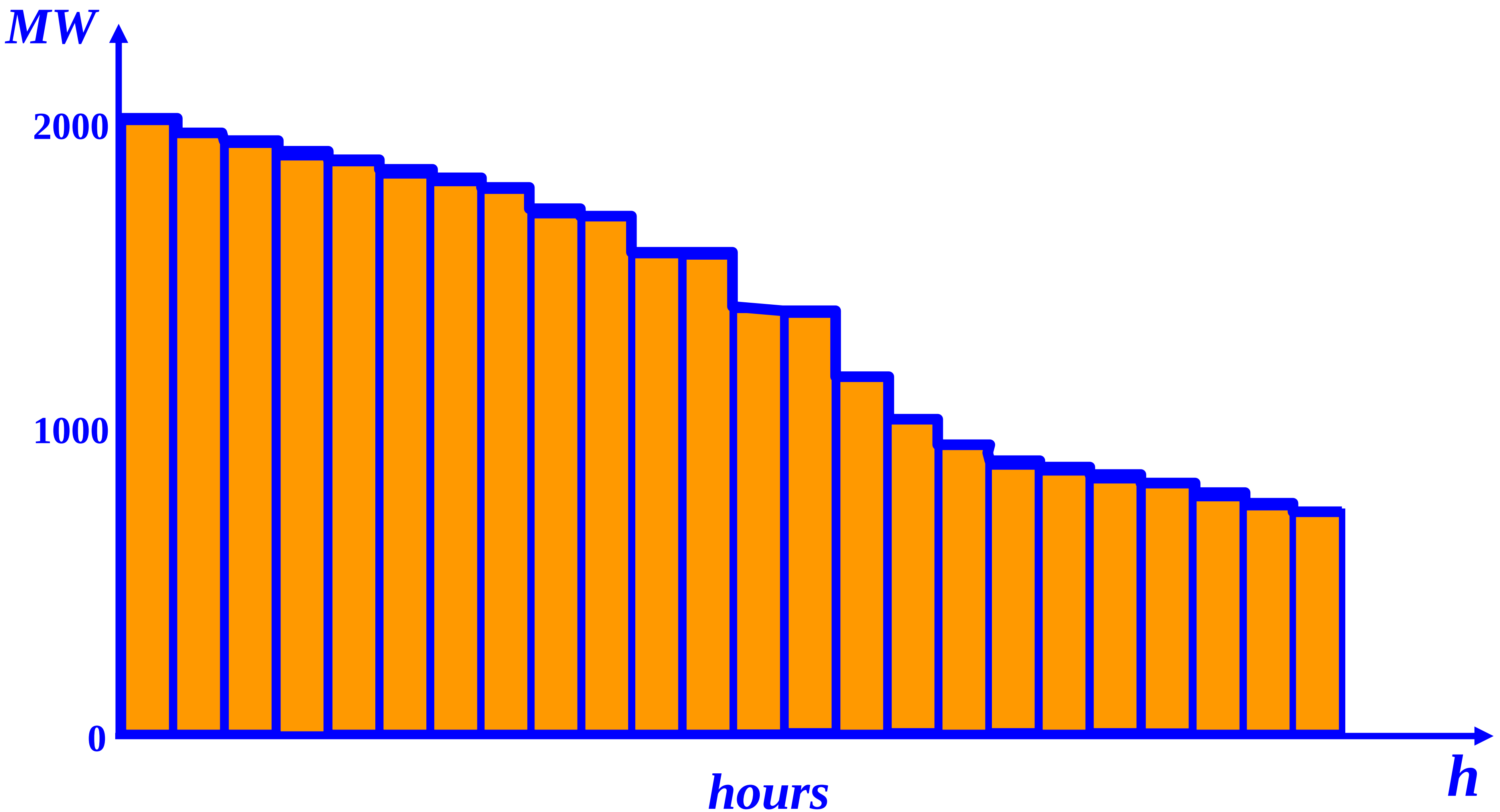


FRIDAY HOURLY LOAD VALUES

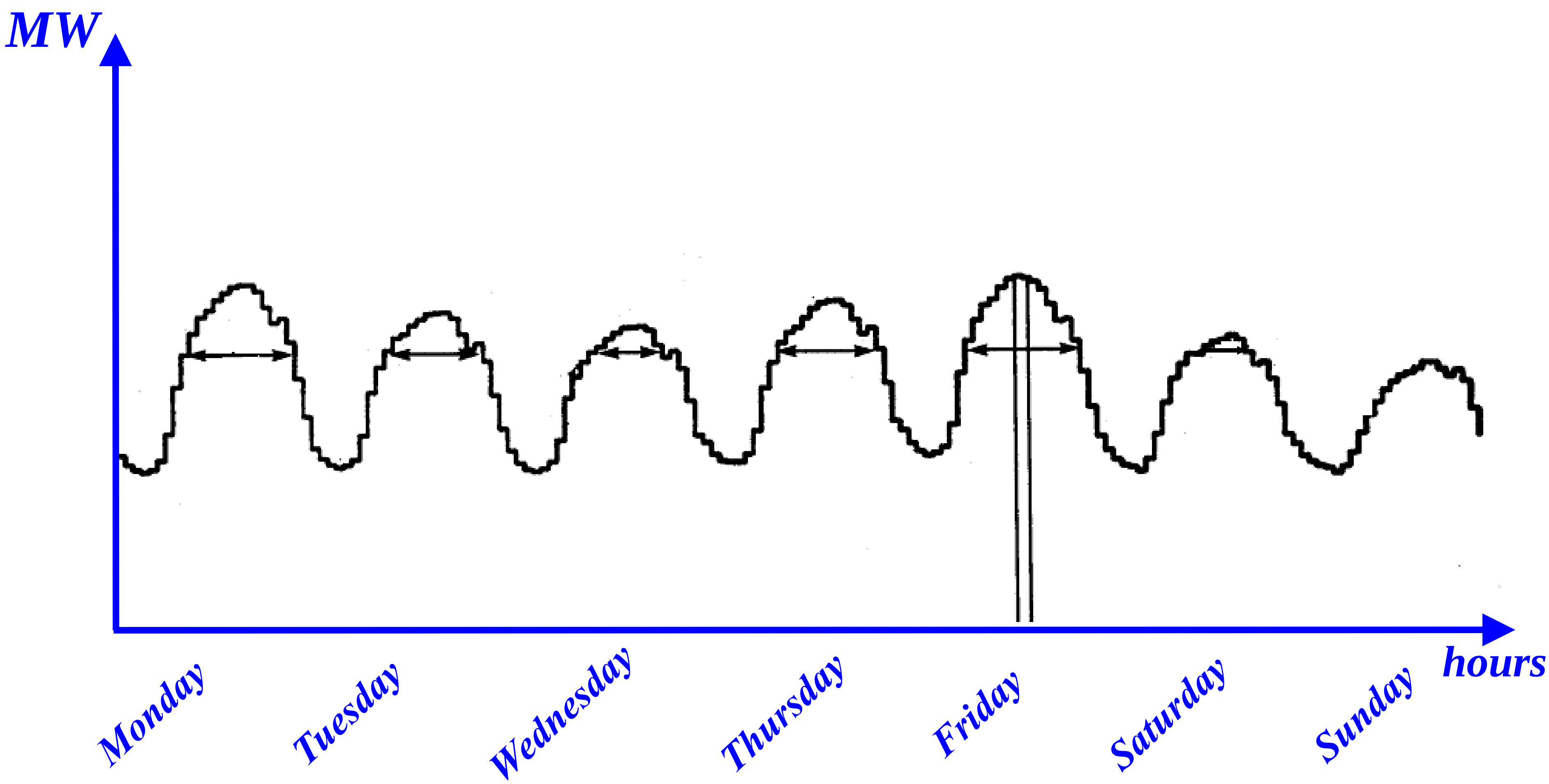
hour ending at	*load (MW)*
01:00	**820**
02:00	**840**
03:00	**885**
04:00	**1,010**
05:00	**1,375**
06:00	**1,560**
07:00	**1,690**
08:00	**1,775**
09:00	**1,810**
10:00	**1,875**
11:00	**1,975**
12:00	**2,000**

hour ending at	*load (MW)*
13:00	**1,900**
14:00	**1,850**
15:00	**1,780**
16:00	**1,680**
17:00	**1,550**
18:00	**1,370**
19:00	**1,130**
20:00	**975**
21:00	**875**
22:00	**780**
23:00	**775**
24:00	**750**

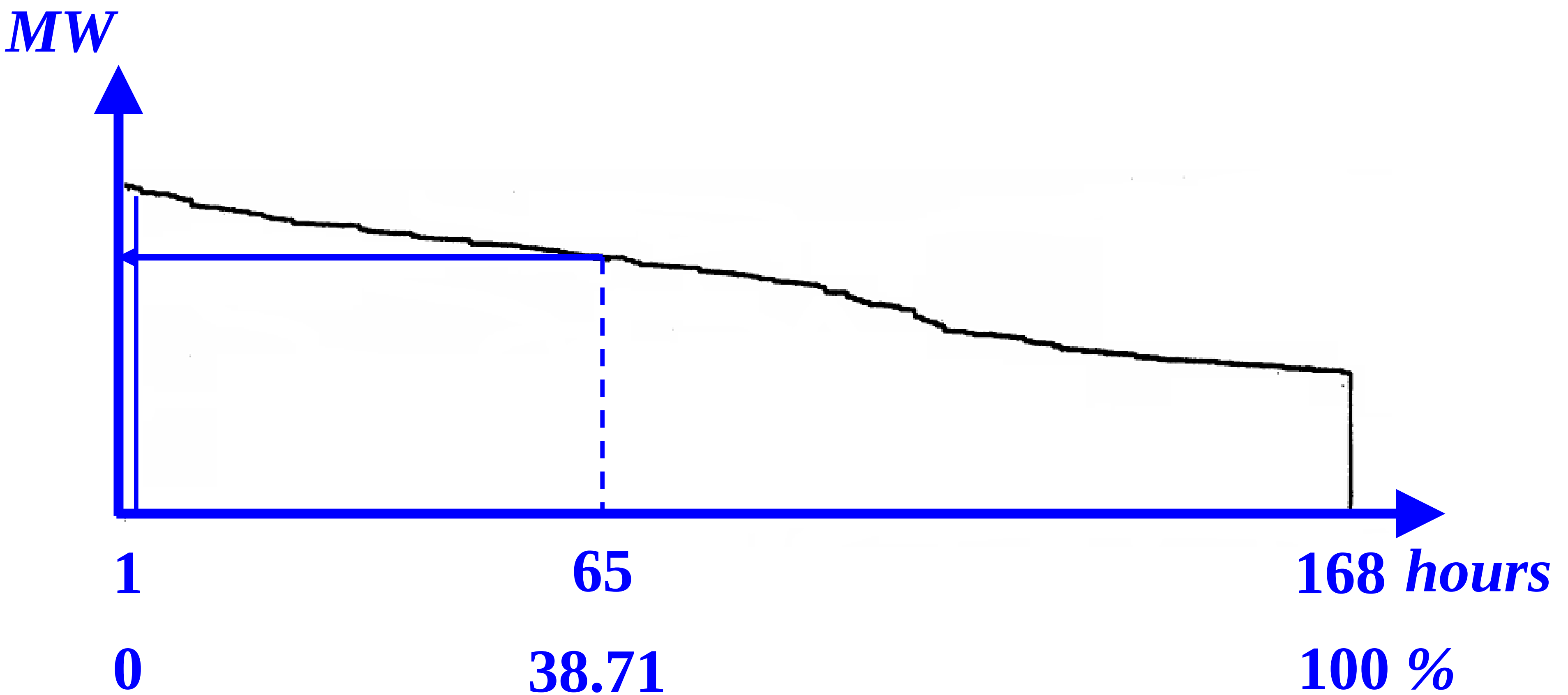
FRIDAY LOAD DURATION CURVE



CHRONOLOGICAL LOAD FOR A SUMMER WEEK



LOAD DURATION CURVE FOR A SUMMER WEEK



LOAD DURATION CURVE CHARACTERISTICS

- **Inability to**
  - **specify the load at any specific hour**
  - **distinguish between weekday and weekend loads**
- **Ability to specify**
  - **the number of hours at which the load exceeds any given value**
  - **the total energy demand for the given period in terms of the area under the *LDC***

CONVENTIONAL GENERATION UNIT ECONOMICS

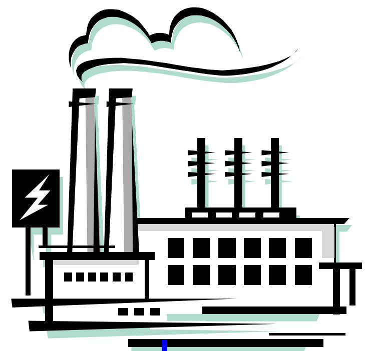
- **The costs of generation by a conventional unit are described by a so-called *input–output curve*, which specifies the amount of input required to obtain a specified level of output**
- **Typically, such curves are obtained from actual measurements and are characterized by their *monotonically non–decreasing* forms**

INPUT – OUTPUT MEASUREMENTS

heat input
(MMBtu/h)

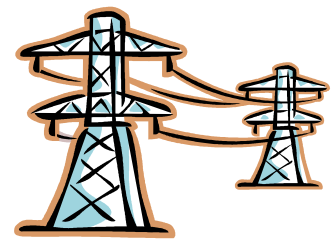
measurement

heat content &
flow–rate of fuel



set control valve points

output
(MWh/h)



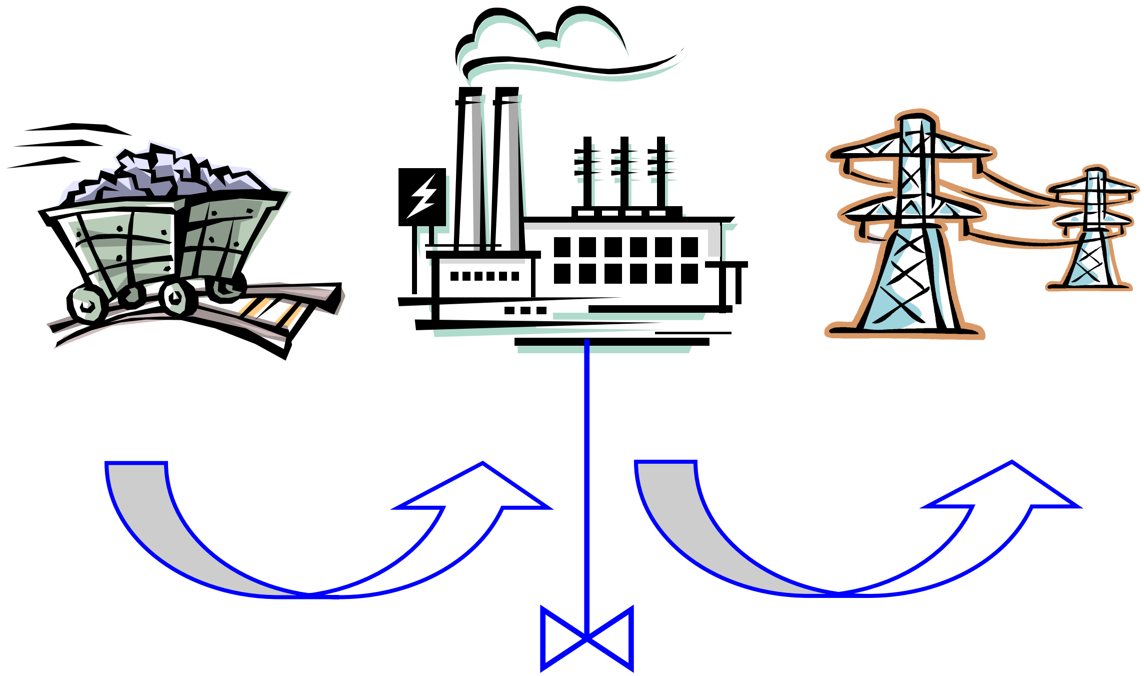
measurement

energy output

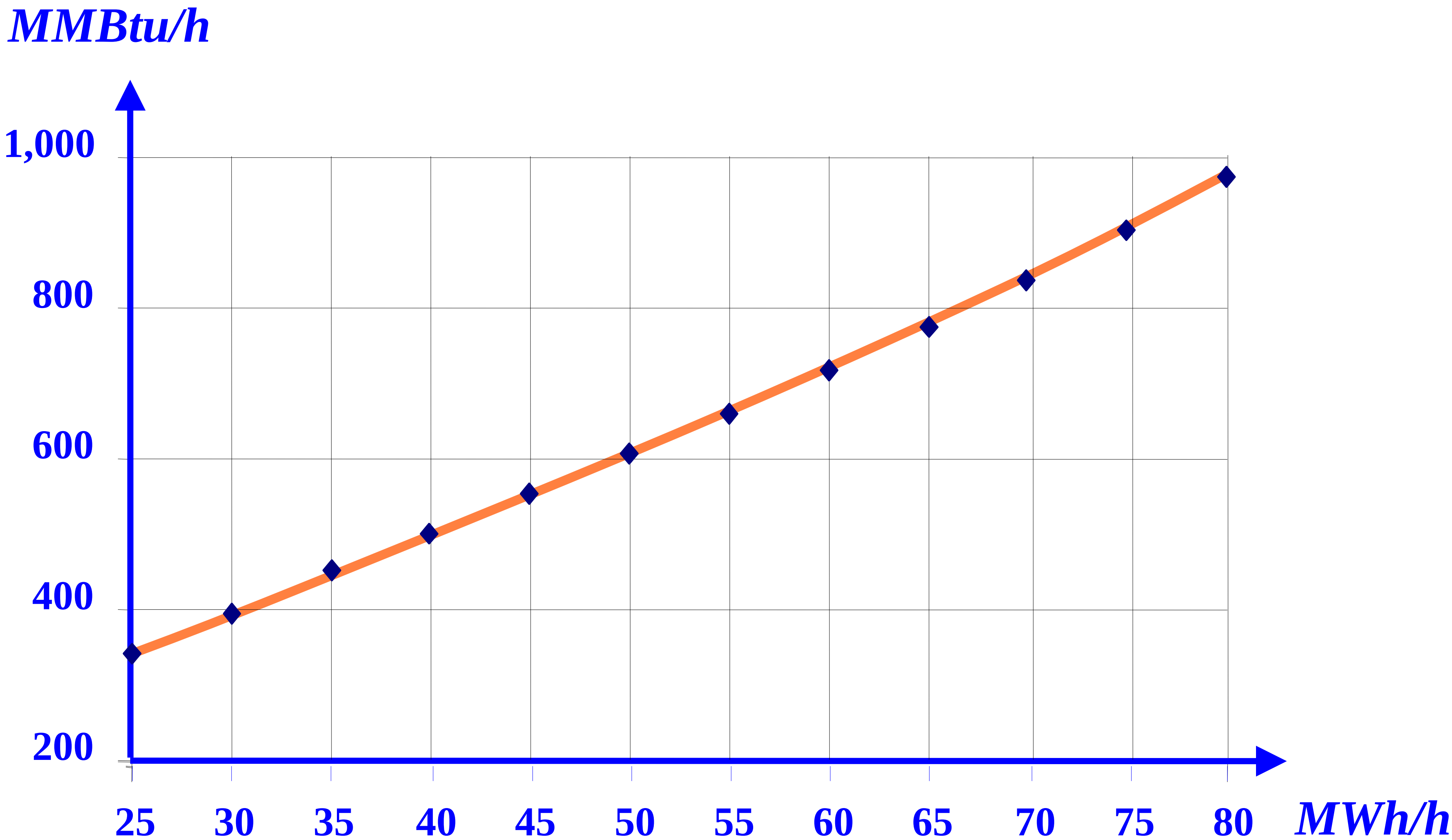
EXAMPLE :

CWLP DALLMAN UNITS 1 AND 2

heat input (MMBtu/h)	*output (MWh/h)*
972	80
901	75
835	70
773	65
715	60
659	55
605	50
552	45
499	40
446	35
392	30
336	25



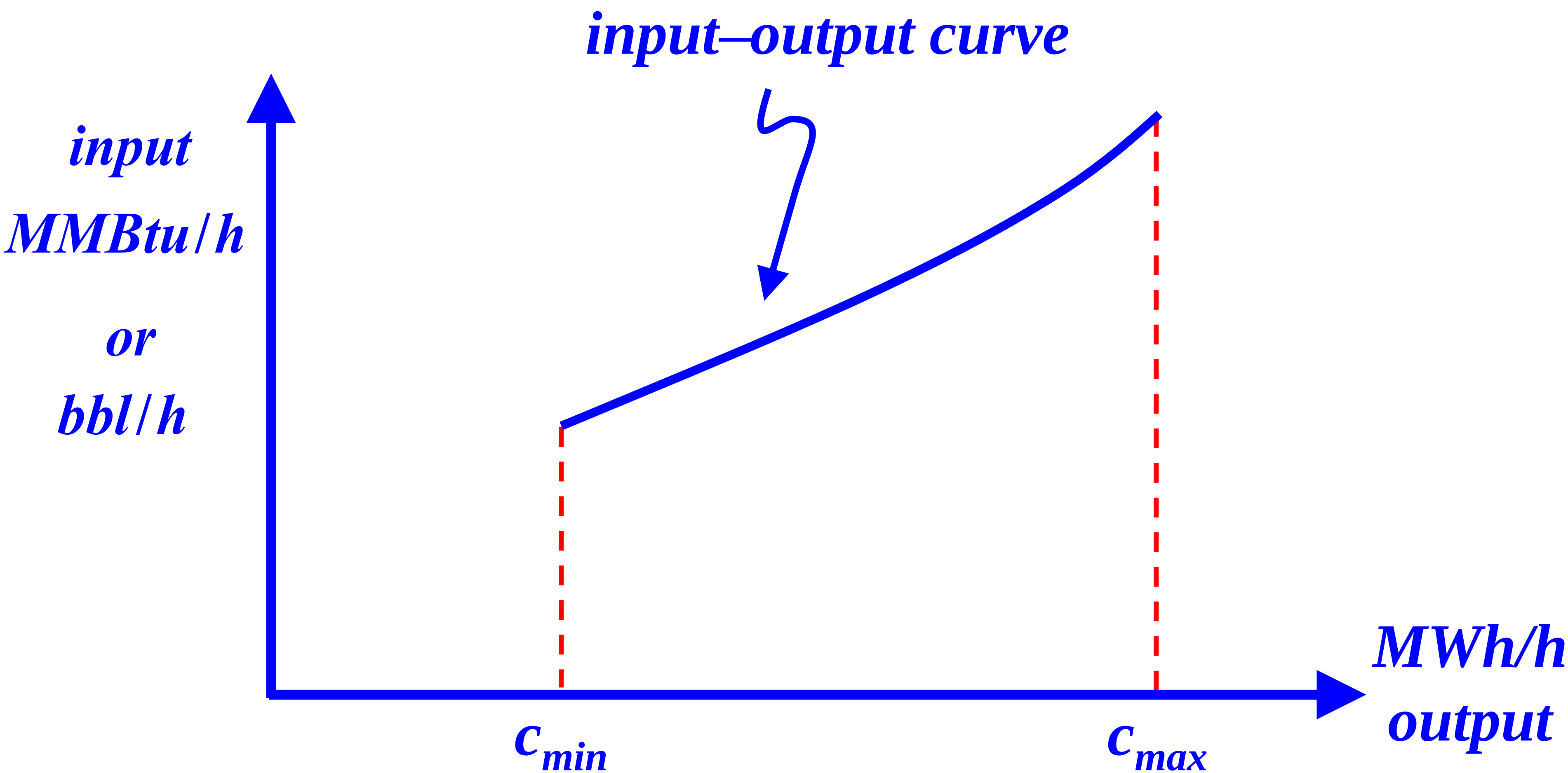
CWLP DALLMAN UNITS 1 AND 2 INPUT – OUTPUT CURVE FITTING



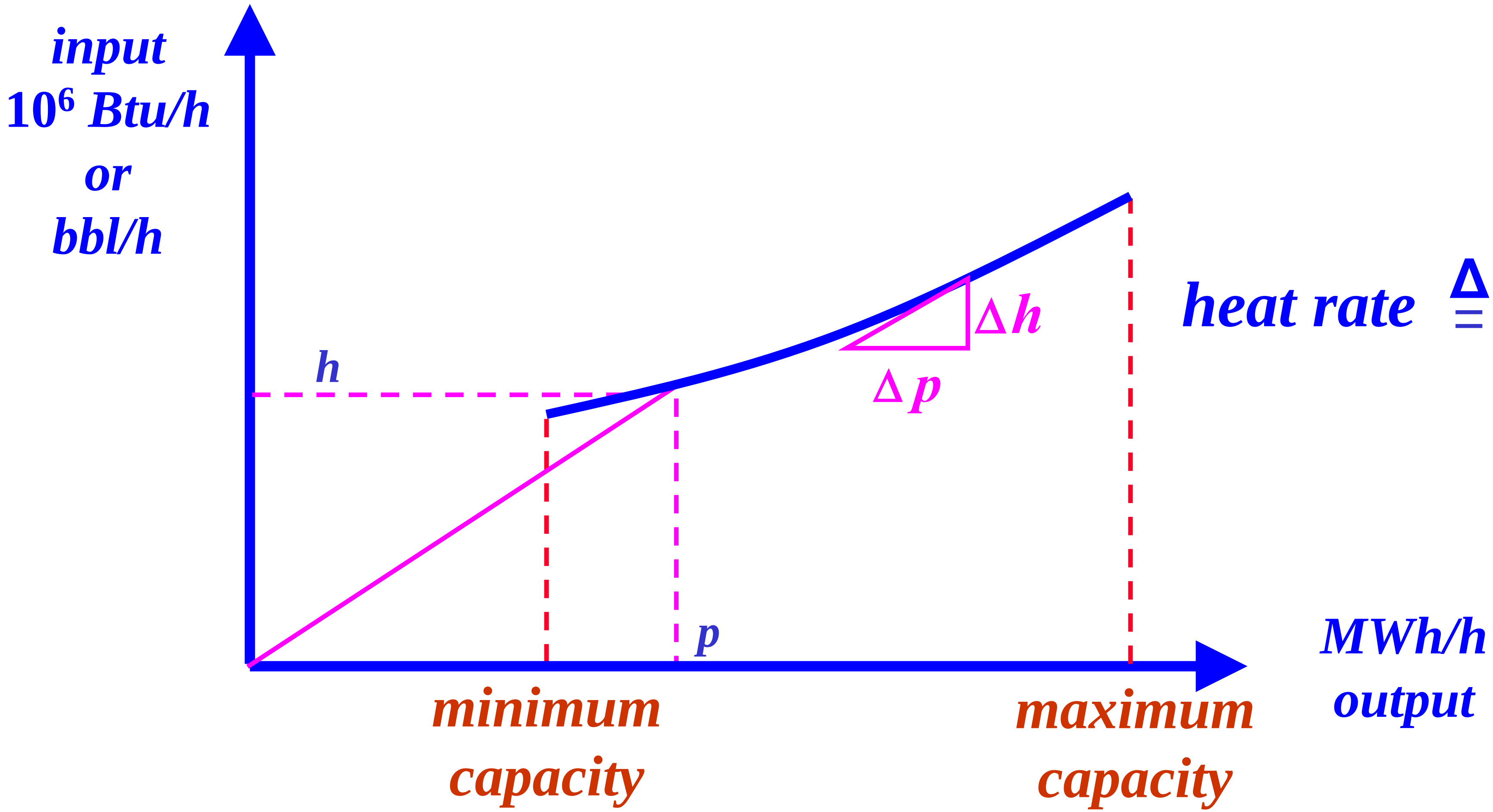
GENERATION UNIT ECONOMICS

- The output is in *MW* and the input is in *bbl/h* or *Btu/h* (volume or thermal heat contents flow rate of the input fuel)
- We may also think of the abscissa in units *$/h* since the costs of the input are obtained via a linear scaling the fuel input by the unit fuel price
- We use the input–output curve to obtain the ***incremental input–output curve*** to determine the costs to generate an additional *MWh* at a specified level of output

GENERATION UNIT ECONOMICS



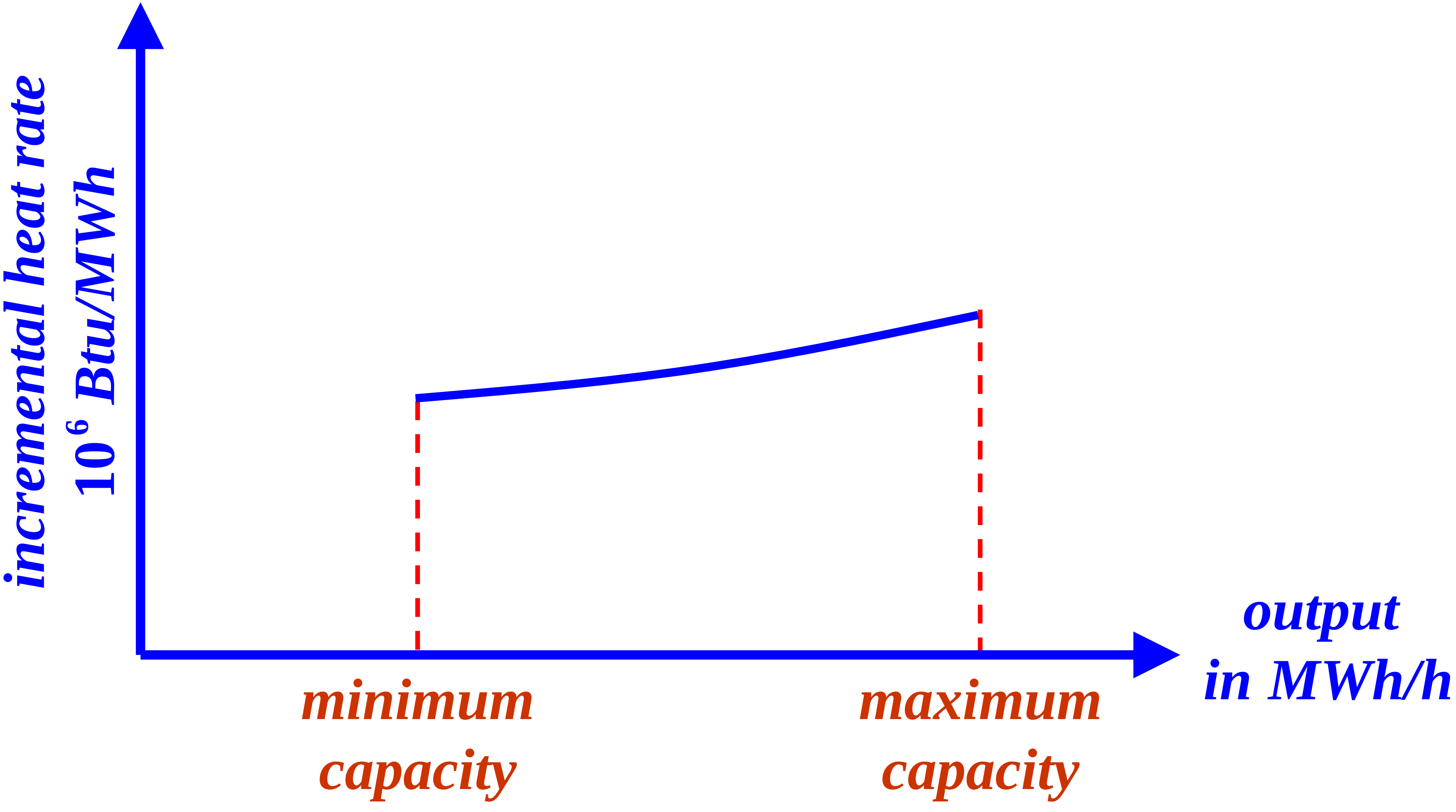
GENERATION UNIT ECONOMICS



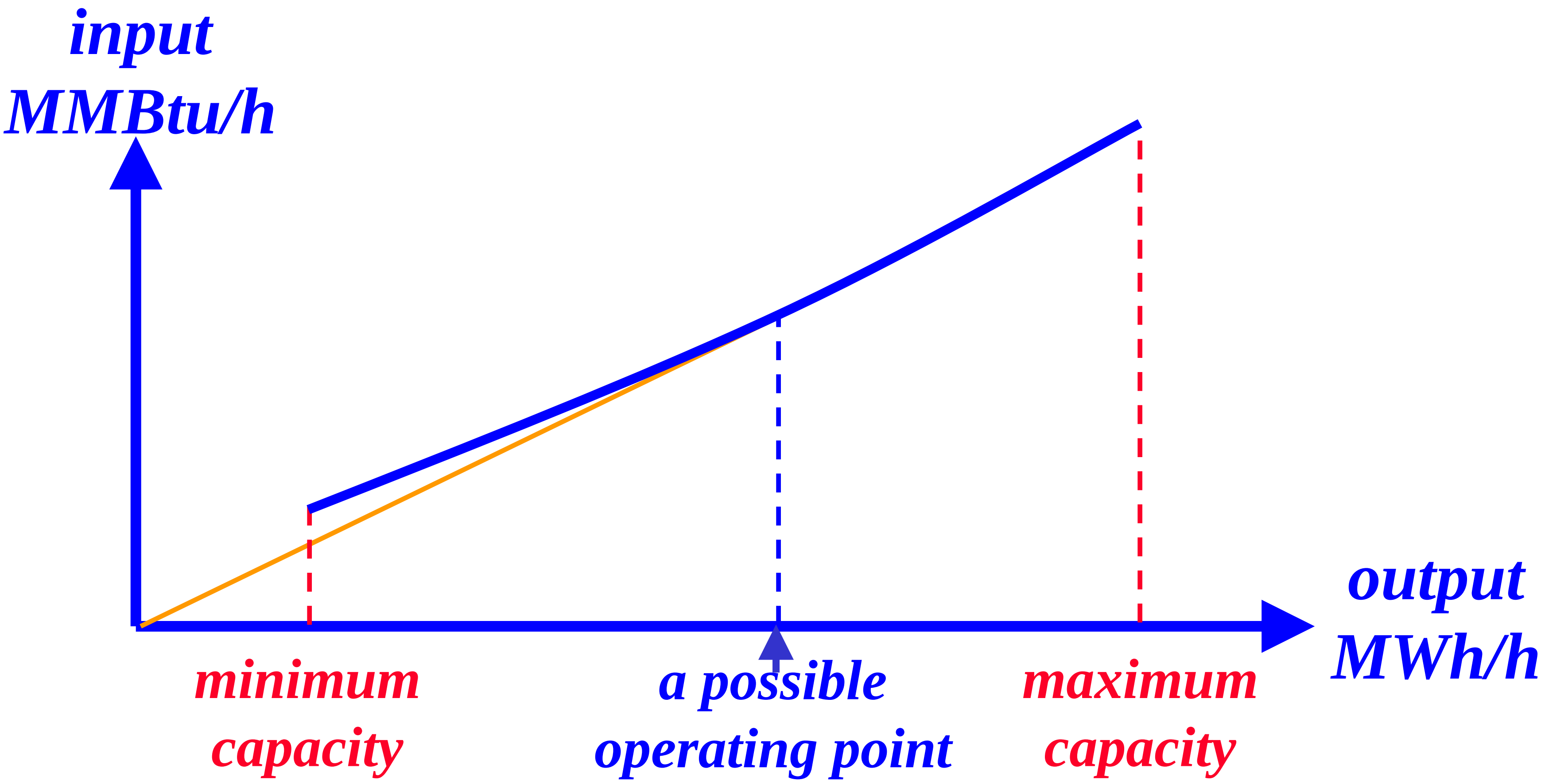
heat rate $\triangleq \frac{h}{p}$

incremental heat rate $= \frac{\Delta h}{\Delta p} =$ *incremental input output*

INCREMENTAL CHARACTERISTICS



HEAT RATE



$$\textit{heat rate} = \frac{\textit{input}}{\textit{output}}$$

$$\textit{incremental heat rate} = \frac{\textit{incremental input}}{\textit{incremental output}}$$

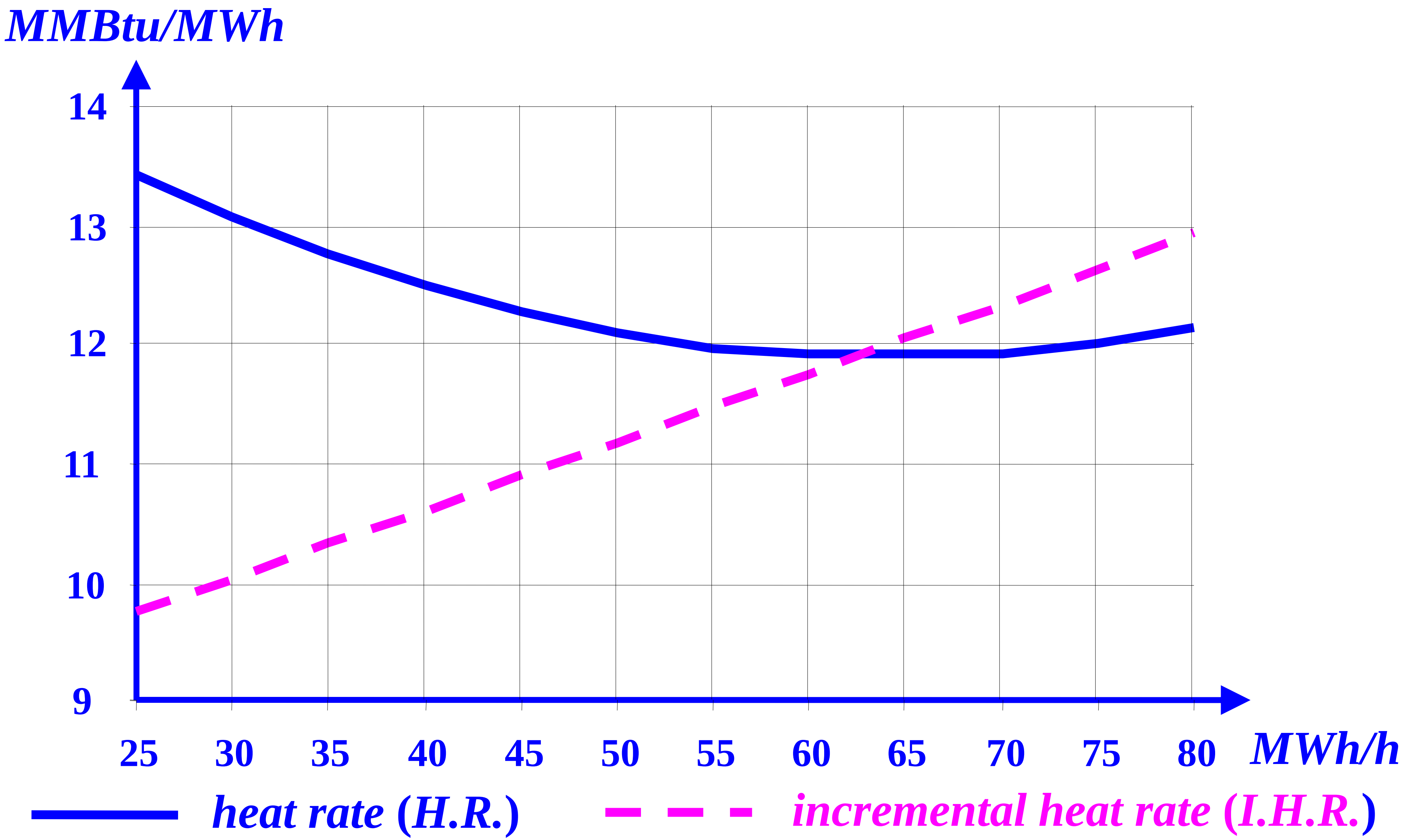
HEAT RATE

- The *heat rate* is a figure of merit widely used in the electric power industry
- The *heat rate* gives the inverse of the efficiency measure of a generation unit since

$$H.R. = \frac{input}{output}$$

- The lower the *H.R.*, the higher is the efficiency of the resource

CWLP DALLMAN UNITS 1 AND 2
H.R. & INCREMENTAL H.R. CURVES



GENERATOR CAPACITY FACTOR

- The amount of energy a generating unit produces is a function of
  - the generator capacity
  - the generator availability
  - the generator loading order to meet the load
- A 100 % available base–loaded unit with c_{max} MW capacity operates around the clock and so during a T–$hour$ period generates total MWh given by

$$\mathcal{E} = c_{max} T$$

GENERATOR CAPACITY FACTOR

- **The maximum unit can generate over *T hours* is**

$$\mathcal{E}_{max} = c_{max} T$$

- **The capacity factor κ of a base-loaded unit is**

$$\kappa = \frac{\mathcal{E}}{\mathcal{E}_{max}} = 1$$

- **A cycling unit exhibits on – off behavior since its loading depends on the system demand; its $\mathcal{E}_{max} = c_{max} T$ exceeds the actual generation since the unit generates only during certain periods**

GENERATOR CAPACITY FACTOR

- **Therefore, a cycling unit has a *c.f.***

$$\kappa = \frac{\mathcal{E}}{\mathcal{E}_{max}} < 1$$

- **For example, a cycling unit of 150 *MW* that operates typically 1,800 *hours* per year with no outages and at full capacity has**

$$\kappa = \frac{150 \cdot 1,800}{150 \cdot 8,760} = \frac{180}{876} = 0.21$$

- **A peaking unit operates only for a few hours each year and consequently has a relatively low *c.f.***

GENERATOR CAPACITY FACTOR

- An expensive peaker may have, say, a *c.f.*

$$\kappa = 5\,\%$$

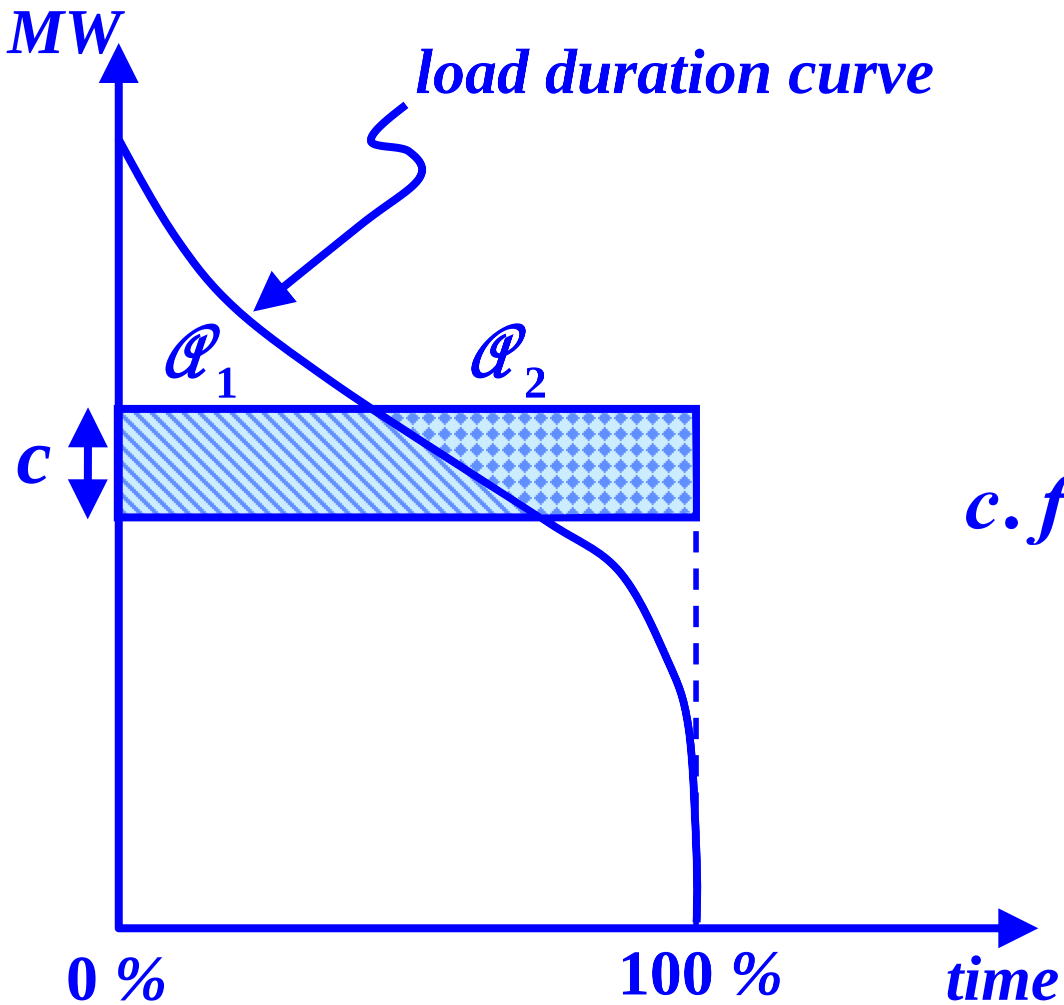
indicating that under perfect availability it operates about 438 hours a year

- Typically, κ is defined on an annual basis

$$\kappa = \frac{annual\ energy\ generated}{maximum\ energy\ generated},$$

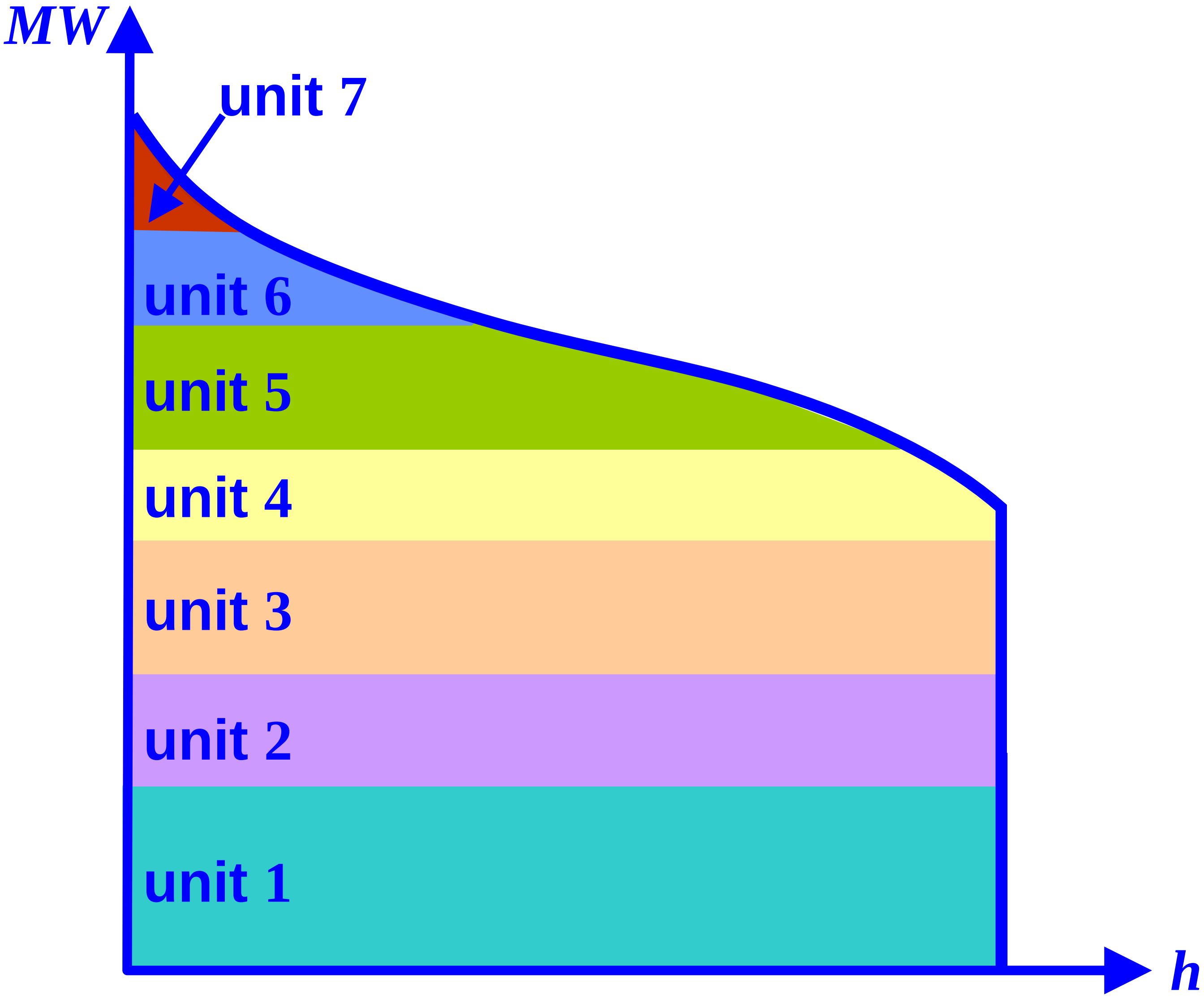
where, the denominator may account for annual maintenance and so the implication is less than 8,760 hours of operation

CAPACITY FACTOR

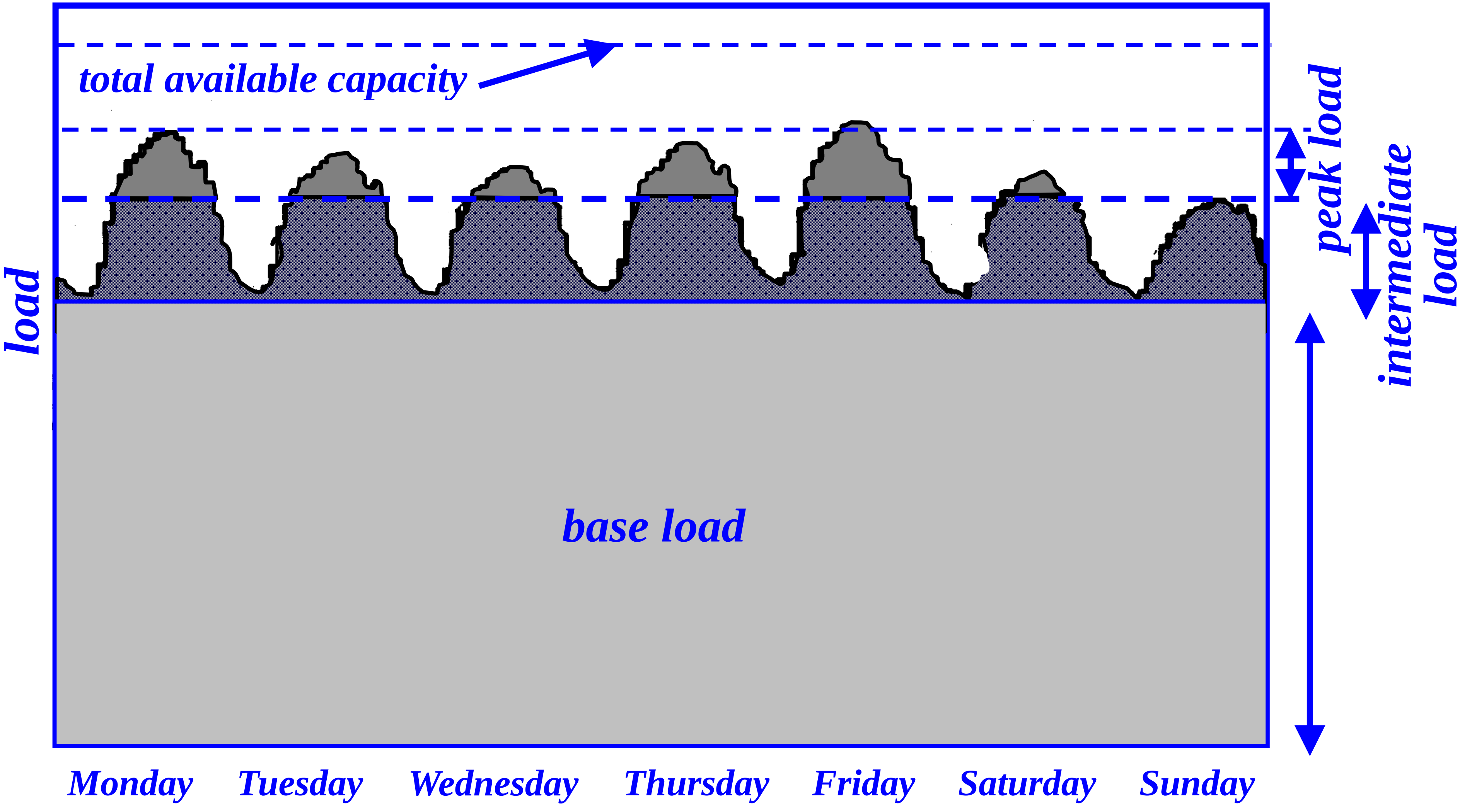


$$c.f. = \frac{\mathscr{A}_1}{\left(\mathscr{A}_1 + \mathscr{A}_2\right)}$$

LOADING OF RESOURCES



LOADING OF RESOURCES



RESOURCE FIXED AND VARIABLE COSTS

- **Fixed costs are those cost elements that are independent of the operation of a resource and are incurred even if the resource is not operating**
- **Typical components of fixed costs are:**
  - **investment or capital costs**
  - **insurance**
  - **fixed *O&M***
  - **taxes**

RESOURCE FIXED AND VARIABLE COSTS

- Variable costs are associated with the actual operation of a resource
- Key components of variable costs are
  - fuel costs
  - variable *O&M*
  - emission costs

ANNUALIZED INVESTMENT OR CAPITAL COSTS

- The *fixed charge rate* annualizes the capital costs to produce a yearly uniform cash–flow set over the life of a resource
- The annual fixed costs are

$$yearly\ costs\ =\ \left(fixed\ costs\right)\cdot\left(fixed\ charged\ rate\right)$$

- Typically, the yearly charge is given on a per unit – kW or MW – basis

ANNUALIZED INVESTMENT OR CAPITAL COSTS

- The fixed charge rate represents the interest on loans, acceptable returns for investors and other fixed cost components: however, each component is independent of the generated *MWh*

- The rate primarily depends on the costs of capital

ANNUALIZED VARIABLE COSTS

- The variable costs are a function of the number of hours of operation of the unit or equivalently of the capacity factor κ
- The annualized variable costs may vary from year to year

$$\begin{matrix} variable \\ costs \end{matrix} = \left[\begin{pmatrix} fuel \\ costs \end{pmatrix} \begin{pmatrix} heat \\ rate \end{pmatrix} + \begin{pmatrix} variable \\ O\,\&\,M\ costs \end{pmatrix} \right] \begin{pmatrix} number\ of \\ hours \end{pmatrix}$$

ANNUALIZED VARIABLE COSTS

- The yearly variable costs explicitly account for fuel cost escalation
- Often, the yearly costs are given on a *per unit* – *kW* or *MW* – basis
- We illustrate these concepts with a pulverized – coal steam plant

EXAMPLE: COAL – FIRED STEAM PLANT

characteristic	*value*	*unit*
capital costs	**1,400**	***$/kW***
heat rate	**9,700**	***Btu/kWh***
fuel costs	**1.5**	***$/MBtu***
variable costs	**0.0043**	***$/kWh***
annual fixed charge rate	**0.16**	—
full output period	**8,000**	***h***

EXAMPLE: COAL – FIRED STEAM PLANT

- The annualized fixed costs per *kW* are

$$\left(1{,}400\ \$/kW\right)\left(0.16\right) = 224\ \$/kW$$

- The initial year annual variable costs per *kW* are

$$\left[\begin{array}{c}\left(1.5\times 10^{-6}\ \$/Btu\right)\left(9{,}700\ Btu/kWh\right) + \\ 0.0043\ \$/kWh\end{array}\right]\left(8{,}000\,h\right)$$

$$= 150.8\,\$/kW$$

EXAMPLE: COAL – FIRED STEAM PLANT

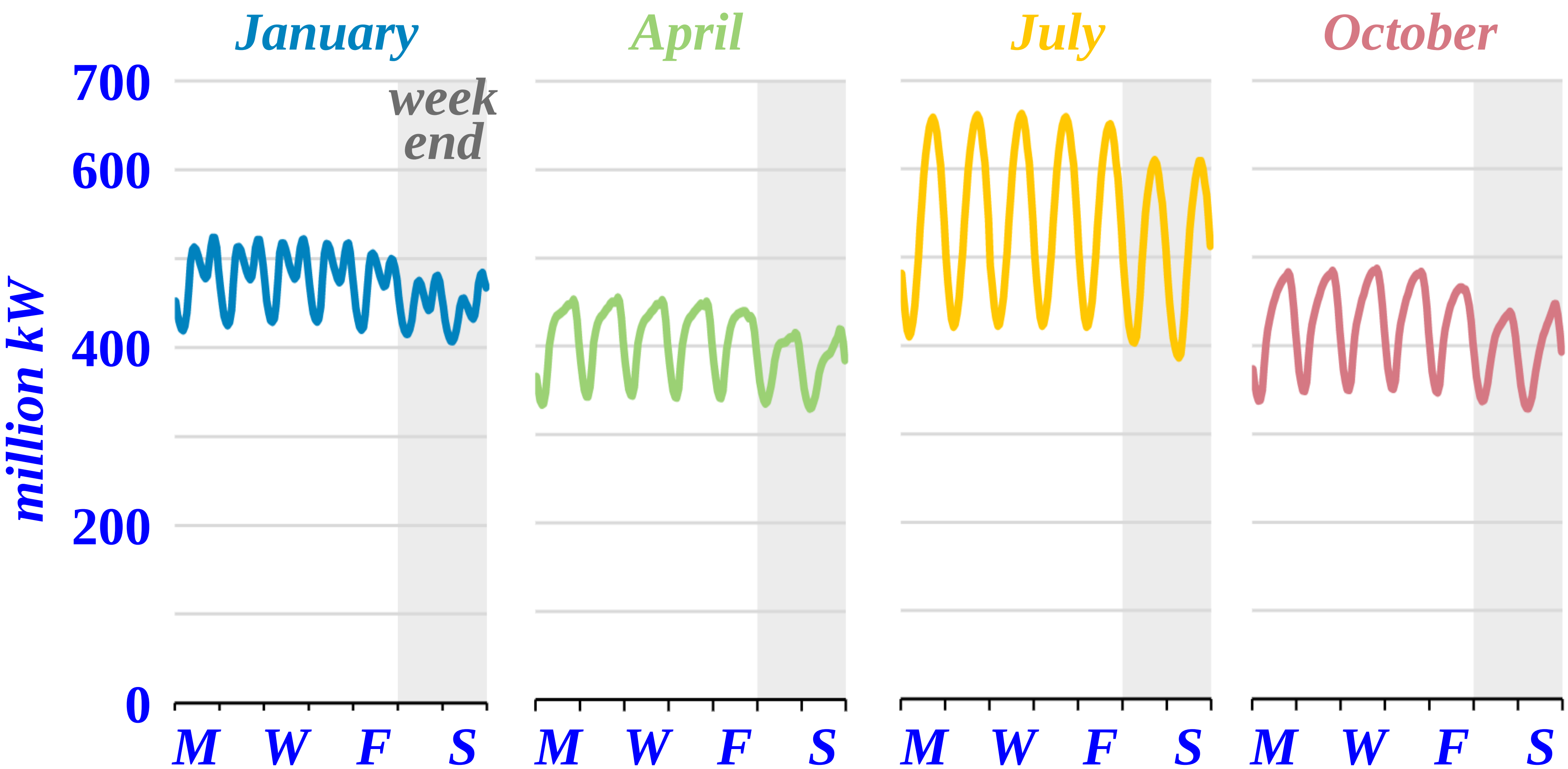
- **Total annual costs for $8{,}000\ h$ are**

$$\frac{\left(224+150.8\right)\$/kW}{8,000\,h}=0.0469\,\$/kWh$$

- **Note, we do the example under the assumption of full output for $8{,}000\ h$ and 0 output for the remaining $760\ h$ of the year**
- **We also neglect any possible outages of the unit and so explicitly ignore any uncertainty in the unit performance**

HOURLY LOADS IN TYPICAL WEEKS

Source: EIA February 21, 2019; available at https://www.eia.gov/todayinenergy/detail.php?id=42915



TYPICAL DAY HOURLY LOADS

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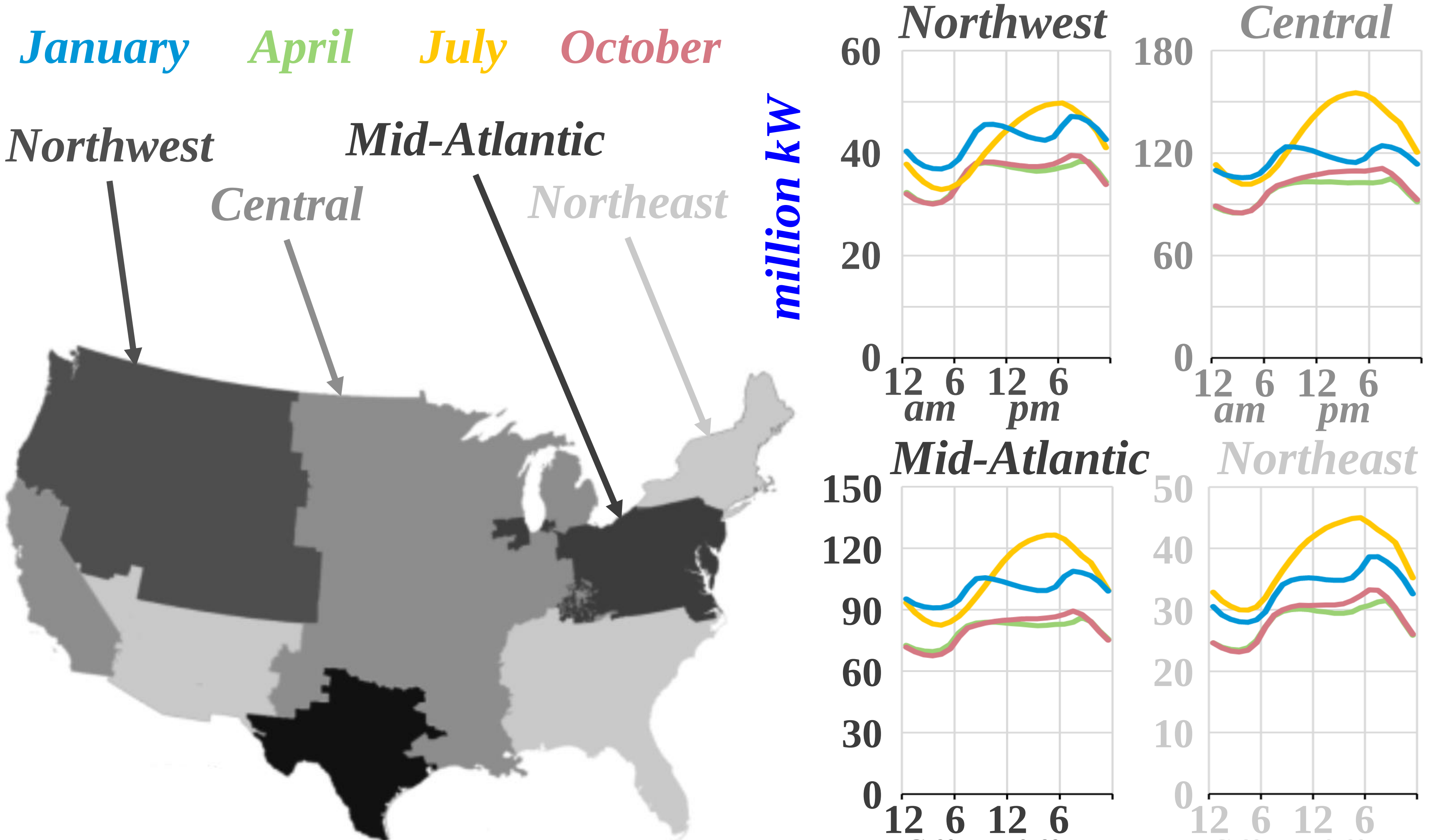

TYPICAL DAY HOURLY LOADS

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