Weather Effects in Energy Seasonal Adjustment

An Application to France Energy consumption

Marie Bruguet[1,2,3]
Ronan Le Saout [4]
Arthur Thomas[1,3]

5th November, 2024 - FAEE PhD Student Workshop 2024

[1] Université Paris-Dauphine, LEDa
[2] Commissariat Général au Développement Durable, SDES
[3] Chaire Economie du Climat
[4] CREST-ENSAI

Context

Motivations

- The Paris Agreement aims to reduce global greenhouse gas emissions
- Energy demand accounts for an average of 77% of total emissions in Europe
- The ”Pluriannual Energy Plan” (PPE) sets the reduction targets for France
- Adjusting demand is crucial for accurate assessments of energy consumption reduction

Motivations

- The Paris Agreement aims to reduce global greenhouse gas emissions
- Energy demand accounts for an average of 77% of total emissions in Europe
- The ”Pluriannual Energy Plan” (PPE) sets the reduction targets for France
- Adjusting demand is crucial for accurate assessments of energy consumption reduction

Motivations

- The Paris Agreement aims to reduce global greenhouse gas emissions
- Energy demand accounts for an average of 77% of total emissions in Europe
- The "Pluriannual Energy Plan" (PPE) sets the reduction targets for France
- Adjusting demand is crucial for accurate assessments of energy consumption reduction

Motivations

- The Paris Agreement aims to reduce global greenhouse gas emissions
- Energy demand accounts for an average of 77% of total emissions in Europe
- The ”Pluriannual Energy Plan” (PPE) sets the reduction targets for France
- Adjusting demand is crucial for accurate assessments of energy consumption reduction

Motivations

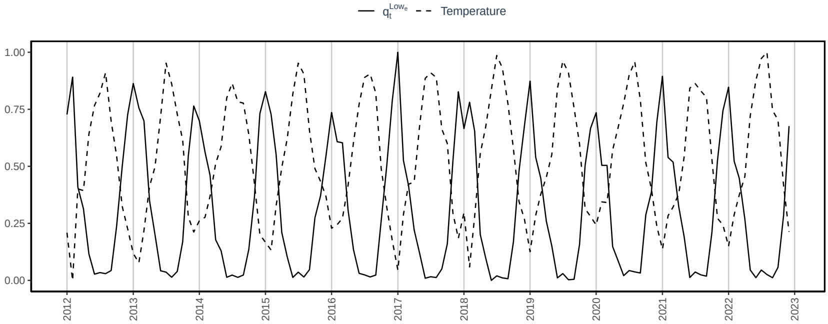


Figure 1: Temperatures and low tension electricity demand normalised by month - France

▸ Correlations

Heating Degree Days

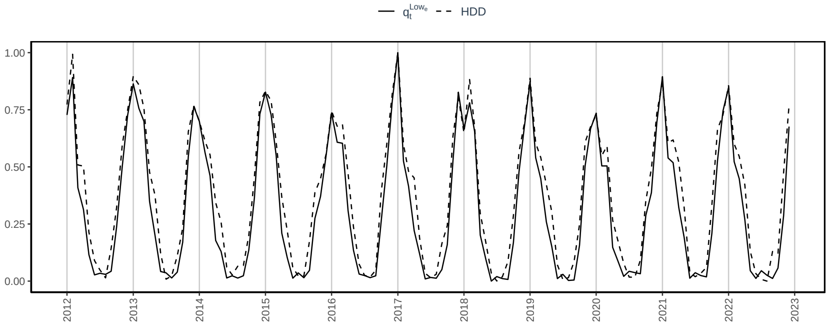


Figure 2: Heating Degree Days and low tension electricity demand normalised by month - France

$$HDD = \begin{cases} T_{base} - T_t \ if \ T_t < T_{base} \\ 0 \ otherwise \end{cases} \tag{1}$$

T_{base} the outside temperature at which agents decide to heat (cooldown) their premises

Research questions

Main question

How do we define the base temperature ?

- Some literature has explored the definition of T_{base} at an aggregate level (Thom, 1954; De Azevedo et al., 2015; Bessec and Fouquau, 2008)
- The choice of T_{base} is rarely justified at the aggregate level in the applied literature and set to $18C$ for HDD and $21C$ for CDD out of habits

  ▸ Applied literature
- The stability of the T_{base} can be challenged:

Research questions

Main question

How do we define the base temperature ?

- Some literature has explored the definition of T_{base} at an aggregate level (Thom, 1954; De Azevedo et al., 2015; Bessec and Fouquau, 2008)

- The choice of T_{base} is rarely justified at the aggregate level in the applied literature and set to $18C$ for HDD and $21C$ for CDD out of habits
  ▸ Applied literature

- The stability of the T_{base} can be challenged:

Research questions

Main question

How do we define the base temperature ?

- Some literature has explored the definition of T_{base} at an aggregate level (Thom, 1954; De Azevedo et al., 2015; Bessec and Fouquau, 2008)
- The choice of T_{base} is rarely justified at the aggregate level in the applied literature and set to $18C$ for HDD and $21C$ for CDD out of habits

▸ Applied literature

- The stability of the T_{base} can be challenged:

Research questions

Main question

How do we define the base temperature ?

- Some literature has explored the definition of T_{base} at an aggregate level (Thom, 1954; De Azevedo et al., 2015; Bessec and Fouquau, 2008)
- The choice of T_{base} is rarely justified at the aggregate level in the applied literature and set to $18C$ for HDD and $21C$ for CDD out of habits

  ▸ Applied literature
- The stability of the T_{base} can be challenged:
  - over time (Cui et al., 2023; Kennard et al., 2022; Sailor and Pavlova, 2003)

Research questions

Main question

How do we define the base temperature ?

- Some literature has explored the definition of T_{base} at an aggregate level (Thom, 1954; De Azevedo et al., 2015; Bessec and Fouquau, 2008)
- The choice of T_{base} is rarely justified at the aggregate level in the applied literature and set to $18C$ for HDD and $21C$ for CDD out of habits

  ▸ Applied literature
- The stability of the T_{base} can be challenged:
  - over time (Cui et al., 2023; Kennard et al., 2022; Sailor and Pavlova, 2003)
  - over space (Bessec and Fouquau, 2008)

Research questions

Main question

How do we define the base temperature ?

- Some literature has explored the definition of T_{base} at an aggregate level (Thom, 1954; De Azevedo et al., 2015; Bessec and Fouquau, 2008)
- The choice of T_{base} is rarely justified at the aggregate level in the applied literature and set to $18C$ for HDD and $21C$ for CDD out of habits

  ▸ Applied literature
- The stability of the T_{base} can be challenged:
  - over time (Cui et al., 2023; Kennard et al., 2022; Sailor and Pavlova, 2003)
  - over space (Bessec and Fouquau, 2008)
  - over weather indicator selection (Lefieux, 2007; Lundström, 2017)

Preview of results

Contributions

- Introduction of a **General Weather Indicator (GWI)**
- **An econometric framework**: a two-steps procedure using Clustering and Penalisation
- Applying the procedure to **France's energy demand**

Contributions

- Introduction of a **General Weather Indicator (GWI)**
- **An econometric framework**: a two-steps procedure using Clustering and Penalisation
- Applying the procedure to **France's energy demand**

Contributions

- Introduction of a **General Weather Indicator (GWI)**
- **An econometric framework**: a two-steps procedure using Clustering and Penalisation
- Applying the procedure to **France's energy demand**

Results

- For the 2012-2022 period, we define a base temperature of **15** C for France
- Felt temperature : **wind strength and sunlight duration** can significantly explain variations in energy demand

Results

- For the 2012-2022 period, we define a base temperature of $\mathbf{15} C$ for France
- Felt temperature : **wind strength and sunlight duration** can significantly explain variations in energy demand

Econometric Framework

To construct adjusted time series, accounting for seasonality, working day effects, and weather variations, the recommended econometric approach is based on reg SARIMA (Eurostat)

$$\begin{cases} q_t = \beta GWI_t + \alpha_1 ly_t + \alpha_2 wd_t + x_t \\ \Phi(B^s)\delta(B^s)x_t = \Theta(B^s)a_t \end{cases} \tag{2}$$

- q_t an energy demand variable over T observations
- GWI_t *General Weather Indicator* a vector of HDV^0 and CDV^0
- β vector of weather sensitivity coefficients
- $(ly_t; wd_t)$ working days
- $\Phi(B^s); \delta(B^s); \Theta(B^s)$ polynomials for SARIMA$(1,0,1)(0,1,1)$
- a_t adjusted time series following a $N(\mu_a, \sigma_a^2)$ distribution

▸ HDV^0 and CDV^0

Two-steps statistical procedure

Two-steps statistical procedure

- Step 1 - Discover the set of potential heating and cooling days variables

  K-Means clustering algorithm to detect regime switching behavior

  ▸ Clustering

Step 1

◂ Return

- Cluster the observations within a 2-dimensional space between demand q_t and one of the n weather variables denoted by w_t^k
- Use of K-means algorithm (MacQueen, 1967) and the Within Sum of Square criterion (WSS)

$$WSS = \sum_{j=1}^{k} \sum_{t=1}^{n_k} ||d_t - \bar{cj}||^2 \qquad (3)$$

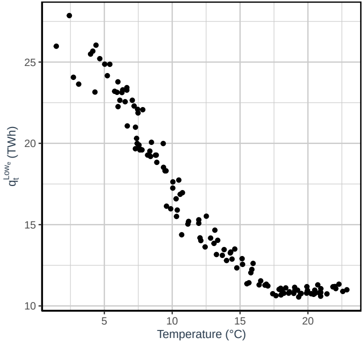


Figure 3: $q_t^{Low_e}$ against temperatures - France

Two-steps statistical procedure

- Step 1 - Discover the set of potential heating and cooling days variables

  K-Means clustering algorithm to detect regime switching behavior

  ▸ Clustering

- Step 2 - Define the optimal vector of heating and cooling days variables

  LASSO regression as a penalisation method to uncover the optimal vector

  ▸ Penalisation

Step 2

◂ Return

The combination of HDV and CDV is defined as the optimal combination highlighted by the LASSO penalisation process

$$\begin{cases} q_t = \beta^* X_t + \varepsilon_t \\ \min \sum^t (q_t - \hat{q}_t)^2 + \lambda ||\beta||_k \end{cases} \tag{4}$$

- q_t an energy demand variable with T observations
- X_t vector of weather regressors containing all potential *HDV* and *CDV*
- λ regularization term to penalize the less significant regressors
- β^* vector of penalised weather sensitivity coefficients (β_k^*)
- ε_t white noise following a $N(\mu_\epsilon, \sigma^2_{\epsilon_t})$ distribution

We propose to define the general weather indicator (GWI (5)) derived from a combination of Heating Days Variable (HDV) and Cooling Days Variable (CDV).

General Weather Indicator

$$GWI_{q_t} = [1_{\beta_k^* \neq 0} \times HDV_{q_t, w_t^k}; 1_{\beta_k^0 \neq 0} \times CDV_{q_t, w_t^k}] \quad (5)$$

- HDV_{q_t, w_t^k} is the heating days variable of the energy demand q_t for the weather variable w_t^k
- CDV_{q_t, w_t^k} is the cooling days variable of the energy demand q_t for the weather variable w_t^k
- $1_{\beta_k^* \neq 0}$ is a dummy variable taking the value 1 if the corresponding heating or cooling variable is selected and 0 if not

Application : France Energy demand

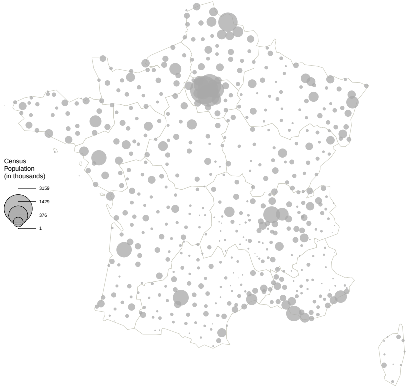
Table 1: Description of energy demand series - (2012-2022)

Series		Sector
Electricity - Low voltage	$q_t^{Low_e}$	Proxy for residential demand (80%)
Electricity - Medium voltage	$q_t^{Med_e}$	Proxy for tertiary demand (58%)
Electricity - High voltage	$q_t^{High_e}$	Proxy for industrial demand (81%)
Gas - Distributed	$q_t^{Low_g}$	Proxy for residential and tertiary demand (74%)
Gas - Transported	$q_t^{High_g}$	Proxy for industrial demand (94%)

Table 2: Description of weather series - (2012-2022)

Series		Units (/24h)
Temperature	*temp*	Average temperature in C
Sunlight duration	*sunlight*	Duration of sunshine in minutes
Wind strength	*wind*	Wind speed in m/s
Amount of rain	*rain*	Rain level in millimeters
Cloud cover	*cloud*	Number of days with a sky overcast $>$ 80% height

- 539 stations selected in metropolitan territory
- Assignment of a single weather station to each municipality
- Weighting of stations by population *(2020 Census)*



Insee, 2020 & Météo France, 2023
Bruguet, 2024

Two-steps procedure : focus on residential electricity demand

Step 1

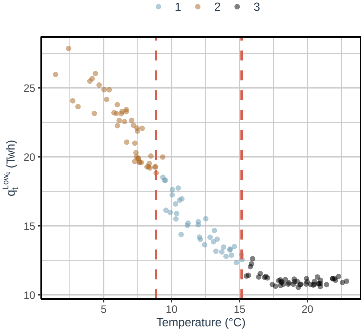


Figure 4: $q_t^{Low_e}$ as a function of temperatures - France

Step 2

Table 3: Definition of *GWI* for $q_t^{Low_e}$ - (2012-2022)

	Threshold	LASSO
temp	9	0
temp	15	1
wind	3	1
wind	3.5	0
sunlight	300	0
sunlight	400	1
rain	2	0
cloud	24	0

Notes: The *K-means* column provides thresholds detected by the clustering method, and the *LASSO* column indicates 0 if the threshold was penalised and 1 if the threshold is statistically significant.

Seasonal and weather adjustment

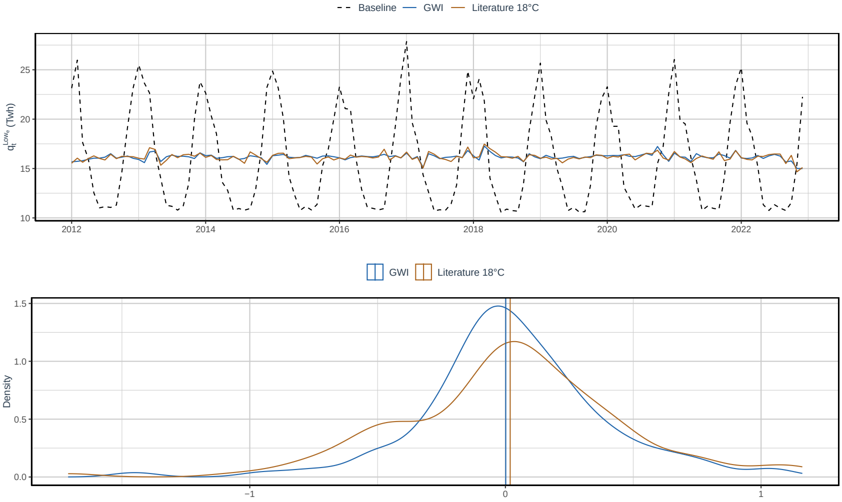


Figure 5: $q_t^{Low_e}$ seasonal and weather adjustment

Economic interpretation

Sectorial results

- **Residential Sector**

  Highly sensitive to the felt temperature variations, primarily due to heating needs

  ▸ Response Functions for q_t^{Lowe}

- **Tertiary Sector**

  Moderate sensitive to the felt temperature variations, due to heating but also cooling needs

- **Industrial Sector**

  Low temperature sensitivity, as energy use is driven more by production activities

Sectorial results

- **Residential Sector**
  Highly sensitive to the felt temperature variations, primarily due to heating needs
  ▸ Response Functions for q_t^{Lowe}
- **Tertiary Sector**
  Moderate sensitive to the felt temperature variations, due to heating but also cooling needs
- **Industrial Sector**
  Low temperature sensitivity, as energy use is driven more by production activities

Sectorial results

- **Residential Sector**

  Highly sensitive to the felt temperature variations, primarily due to heating needs

  ▸ Response Functions for q_t^{Lowe}

- **Tertiary Sector**

  Moderate sensitive to the felt temperature variations, due to heating but also cooling needs

- **Industrial Sector**

  Low temperature sensitivity, as energy use is driven more by production activities

Robustness

Robustness

- **Regional frequency**
  Regional heterogeneity but we recover the mean national base temperature at 15 C
  ▸ Regional

- **Daily frequency**
  National base temperature at 15 C with increased importance of the felt temperature

- **Timing selection**
  The LASSO selection differs according to the time window studied

Conclusion

Conclusion

Contributions

- Introduced a **General Weather Indicator (GWI)**
- Applied this methodology to **France's** energy demand

Results

- National base temperature of **15** C for France for the period 2012-2022
- **Wind strength and sunlight duration** can significantly explain variations in energy demand
- **Heterogeneity** in weather response across different economic and administrative sectors

Thank you for your attention

email : marie.bruguet@dauphine.eu
website : mbruguet.github.io

References i

References

Bessec, M., Fouquau, J., 2008. The non-linear link between electricity consumption and temperature in Europe: A threshold panel approach. Energy Economics 30, 2705–2721.

Cui, X., Gafarov, B., Ghanem, D., Kuffner, T.A., 2023. On model selection criteria for climate change impact studies. Journal of Econometrics , 105511.

De Azevedo, J.A., Chapman, L., Muller, C., 2015. Critique and suggested modifications of the degree days methodology to enable long-term electricity consumption assessments: a case study in Birmingham, UK. Meteorological Applications 22, 789–796.

Kennard, H., Oreszczyn, T., Mistry, M., Hamilton, I., 2022. Population-weighted degree-days: the global shift between heating and cooling. Energy and Buildings 271, 112315.

Lefieux, V., 2007. Modèles semi-paramétriques appliqués à la prévision des séries temporelles. cas de la consommation d'électricité.

Lundström, L., 2017. Adaptive weather correction of energy consumption data. Energy Procedia 105, 3397–3402.

MacQueen, J.B., 1967. Some methods for classification and analysis of multivariate observations. Working Paper 1, 281–297.

Sailor, D.J., Pavlova, A., 2003. Air conditioning market saturation and long-term response of residential cooling energy demand to climate change. Energy 28, 941–951.

Thom, H.C.S., 1954. The rational relationship between heating degree days and temperature. Monthly Weather Review 82.

◂ Return

Table 4: Panel of base temperatures found in the literature and associated justifications

Country	Authors	Journal	Base Temperature (řC)	Justifications
Australia	Badescu and Zamfir (1999)	Energy conversion and management	18	18řC is a common base temperature used in the determination of Heating Degree Days
New Zealand	Badescu and Zamfir (1999)	Energy conversion and management	15,6 and 16	-
Romania	Badescu and Zamfir (1999)	Energy conversion and management	18	18řC is a common base temperature used in the determination of Heating Degree Days
United Kingdom	Badescu and Zamfir (1999)	Energy conversion and management	16	-
Israel	Beenstock et al. (1999)	Energy Economics	10	-
Argentina	Castaneda and Claus (2013)	International journal of climatology	18,3	Thom (1954)
United States of America	Considine (2000)	Resource and Energy Economics	18,3	”A degree-day is the difference between a days average temperature in Fahrenheit and 65řF”
South-Africa	D. Conradie et al. (2018)	Building Research and Information	18	18řC is a common base temperature used in the determination of Heating Degree Days
Italy	De Rosa et al. (2014)	Applied energy	18,3	Thom (1954)
Saudi Arabia	El-Shaarawi and Al-Masri (1996)	Energy	17,8 and 21,1	-
Europe	Eskeland and Mideksa (2010)	Mitigation and adaptation strategies for global change	18 and 22	”A temperature interval is defined as a comfort zone [] i.e., between 18 and 22řC”
Western Europe	Golombek et al. (2012)	Climatic change	18	18řC is a common base temperature used in the determination of Heating Degree Days
Netherlands	Hekkenberg et al. (2009)	Energy Policy	18	18řC is a common base temperature used in the determination of Heating Degree Days
Wordlwide	Isaac and Van Vuuren (2009)	Energy Policy	18	18řC is a common base temperature used in the determination of Heating Degree Days
Turkey	Kadioglu et al. (1999)	Applied Meteorology and Climatology	15	18řC is a common base temperature used in the determination of Heating Degree Days
Hong Kong	Lam (1998)	Energy conversion and management	18,3	Thom (1954)
Greece	Papakostas at al. (2010)	Renewable Energy	15	-
Saudi Arabia	Said (1992)	Engineering And Applied Engineering	18 and 21	-
Ireland	Semmler et al. (2010)	Meterological Applications	18	”This temperatures is the most common base temperature of normally insulated buildings”
Europe	Spinoni et al. (2015)	International journal of climatology	15,5	-
United States of America	Taha (1997)	Energy and buildings	18,3	Thom (1954)
Macedonia	Taseska et al. (2012)	Energy	20	-
United States of America	Thom (1954)	Monthly Weather Review	18,3	Derived from a historical temperature probability function
Spain	Valor et al. (2001)	Journal of Applied Meteorology	15	”Within these two limits a comfort zone was established and no heating or cooling is required”
Spain	Valor et al. (2001)	Journal of Applied Meteorology	18	18řC is a common base temperature used in the determination of Heating Degree Days
United States of America	Deschênes and Greenstone (2011)	American economic journal	18,3	Thom (1954)

◂ Return

Table 5: Correlation between weather and energy time series

	temp	sunlight	wind	rain	cloudiness
$q_t^{Low_g}$	-0.969	-0.825	0.556	0.112	-0.020
	(0.000)	(0.000)	(0.000)	(0.063)	(0.739)
$q_t^{High_g}$	-0.822	-0.764	0.331	0.069	-0.057
	(0.000)	(0.000)	(0.000)	(0.252)	(0.345)
$q_t^{Low_e}$	-0.934	-0.807	0.498	0.130	0.008
	(0.000)	(0.000)	(0.000)	(0.031)	(0.896)
$q_t^{Med_e}$	-0.410	-0.324	0.031	-0.064	0.435
	(0.000)	(0.000)	(0.608)	(0.292)	(0.000)
$q_t^{High_e}$	-0.012	-0.043	0.164	0.044	-0.017
	(0.848)	(0.479)	(0.006)	(0.465)	(0.782)
q_t^{gas}	-0.966	-0.833	0.531	0.107	-0.027
	(0.000)	(0.000)	(0.000)	(0.075)	(0.656)
q_t^{elec}	-0.916	-0.790	0.466	0.100	0.134
	(0.000)	(0.000)	(0.000)	(0.097)	(0.026)

Notes : The table shows the correlation coefficients and the p-values associated. The p-values represent the probability that the null hypothesis, which represents a null correlation, is non-rejected. Thus a null p-value is interpreted as a correlation significantly different from 0. The variables q_t^{gas} and q_t^{elec} represent the sums of the respective variables q_t^{Lowg} , q_t^{Highg} and q_t^{Lowe},q_t^{Mede},q_t^{Highe}.

▸ Return

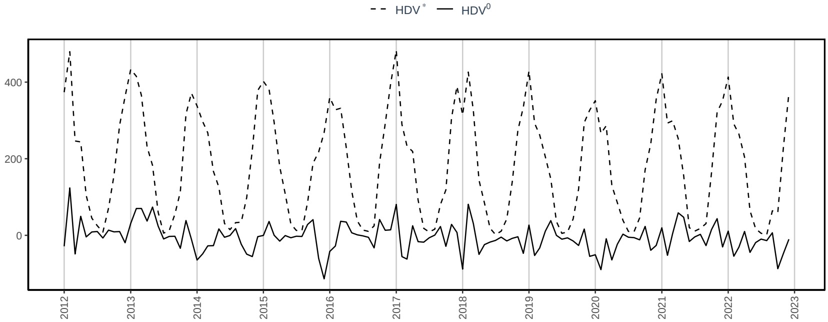
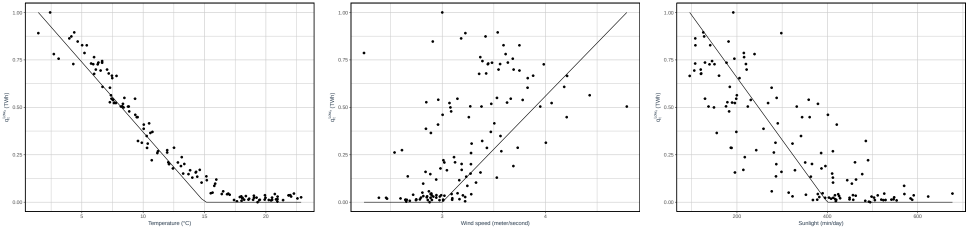


Figure 6: HDV_{temp}

- HDV^* : initial indicator derived from temperature
- HDV^0 : indicator center around 0 using its past mean from 1991 to 2020

◂ Return



(a) (b) (c)

Figure 7: (c) Temperature (d) Wind and (e) Sunlight normalized response function from $q_t^{Low_e}$

Regional results

◂ Return

	Base temperature	Rounded base temperature
Provence-Alpes-Côte d'Azur	13.8	14
Grand Est	14.1	14
Normandie	14.5	14
Hauts-de-France	14.5	14
Bretagne	14.6	15
Centre-Val de Loire	14.7	15
Bourgogne-Franche-Comté	14.7	15
Auvergne-Rhône-Alpes	14.8	15
Pays de la Loire	15.5	16
Île-de-France	15.7	16
Occitanie	16.2	16
Nouvelle-Aquitaine	17.5	18
Mean	15.0	15.2
Weighted mean	15.2	15.3