Modifications of TEB and ISBA for SURFEX V9

This document describes the modification of namelists and model output related to the developments of TEB described in Schoetter et al. (2017), Tornay et al. (2017) and Goret et al. (2019) that will be included in SURFEX V9. The differences are explained with respect to SURFEX V8.0.

1 Human thermal comfort indicator UTCI in rural areas

The human thermal comfort indicator UTCI that is already available for a person walking in a representative street canyon (TOWN-TEB tile of SURFEX) is also calculated for a person walking in the rural environment (NATURE-ISBA tile of SURFEX). Although people might spend most of their time inside buildings or within the urban environment, the UTCI in rural areas is useful for creating UTCI maps. The methodolody is the same as for the UTCI in TEB. The geometry is simpler since there is no need to calculate the view factors with respect to walls, etc. The view factor of the ground and sky or both equal to 0.5. Similar to TEB, the UTCI for a person walking in the sun is calculated by using the full shortwave radiation (direct and scattered) fields whereas the UTCI in the shade is calculated by considering only the scattered shortwave radiation.
In the UTCI calculations (TEB and ISBA) it is assumed that the scattered shortwave and the longwave radiation are isotropic, which is a major uncertainty, since the UTCI is quite sensitive to these variables.

New entry NAM_DIAG_ISBAn.

Type	**Name**	**Default**	**Meaning**
Logical	LUTCI	FALSE	Flag to calculate UTCI in rural areas

New output variables

Name	**Unit**	**Meaning**
UTCI_ISB_SUN	°C	UTCI in sun, rural area
UTCIMSU_ISBA	°C	UTCI in sun, rural area, average between last two output time steps.
UTCI_ISB_SHA	°C	UTCI in shade, rural area
UTCIMSH_ISBA	°C	UTCI in shade, rural area, average between last two output time steps.
TRAD_ISB_SUN	K	Mean radiative temperature for a person in the sun, rural area
TRADMSU_ISBA	K	Mean radiative temperature for a person in the sun, rural area, average between the last two output time steps
TRAD_ISB_SHA	K	Mean radiative temperature for a person in the shade, rural area

TRADMSH_ISBA	K	Mean radiative temperature for a person in the shade, rural area, average between the last two output time steps
TRAD_AGG	K	Mean radiant temperature weight according to sun and shade
UC_IS_SU_STRESSNAME	s	Cumulated time spent in stress range, person in the sun
UC_IS_SH_STRESSNAME	s	Cumulated time spent in stress range, person in the shade
UTCI_OUTAGG	°C	UTCI weight according to sun and shade
UTCI_AG_{heat stress ranges}	s	Cumulated time spent in stress range for person outside
UTCIMSU_TEB	°C	UTCI in sun, town area, average between last two output time steps.
UTCIMSH_TEB	°C	UTCI in shade, town area, average between last two output time steps.
TRADMSU_TEB	K	Mean radiative temperature for a person in the sun, town area, average between the last two output time steps
TRADMSH_TEB	K	Mean radiative temperature for a person in the shade, town area, average between the last two output time steps

2 Separation of input for internal mass and ground floor

The internal mass represents the intermediary floors and walls inside the buildings. In the previous version, no parameters (thickness, heat capacity and conductivity) could be specified for the internal mass. Its thermal parameters have been assumed to be equal to those of the ground floor and its thickness to be half of the thickness of the ground floor. This restricts the representation of the building architecture. For this reason, the characteristics of the internal mass are now separate from those of the ground floor and can be specified via the namelist.

New entry in NAM_TEB

Type	Name	Default	Meaning
INTEGER	NMASS_LAYER	5	Number of layers in internal mass. This refers to the computational grid.

New entries in NAM_DATA_BEM

Type	Name	Default	Meaning
INTEGER	NPAR_MASS_LAYER	1	Number of layers (up to 9) for the internal mass in input data. This does NOT refer to the computational grid. The mass properties are interpolated from the input grid to the computational grid.
REAL (NMASS_MAX=9)	XUNIF_HC_MASS	2.016E+6	Heat capacity of up to 9 mass layers [J/K/m^3]
CHARACTER	CFNAM_HC_MASS		
CHARACTER	CFTYP_HC_MASS		
REAL (NMASS_MAX=9)	XUNIF_TC_MASS	1.95	Thermal conductivity of up to 9 mass layers [W/m/K]
CHARACTER	CFNAM_TC_MASS		
CHARACTER	CFTYP_TC_MASS		
REAL (NMASS_MAX=9)	XUNIF_D_MASS	0.12	Depth of up to 9 mass layers [m]
CHARACTER	CFNAM_D_MASS		
CHARACTER	CFTYP_D_MASS		

3 Dynamical calculation of infiltration

Infiltration is the air exchange between the interior and exterior of the building due to small holes in the building envelope. The infiltration depends on the airtightness of the building and the meteorological conditions. Indeed, the infiltration is caused by pressure differences between the inside and outside. These are caused by differences between indoor and outdoor air temperature (stack effect) and the forcing due to wind (wind effect). In the previous version of TEB, a fixed infiltration rate could be specified via the namelist. However, this neglects the dependency of infiltration on the meteorological conditions. For this reason, we now prescribe the airtightness of the building as model input parameter and calculate the air exchange rate due to infiltration as a function of the meteorological conditions. The detailed equations are given in Appendix A6 of Schoetter et al. (2017).

New entries in NAM_DATA_BEM

Type	**Name**	**Default**	**Meaning**
REAL	XUNIF_N50	8.0	Airtightness of the building [vol./h at 50 Pa]. This parameter is used to calculate the infiltration rate.
CHARACTER	CFNAM_N50		
CHARACTER	CFTYP_N50		

Removed from NAM_DATA_BEM

XUNIF_INF

New output variable

Name	**Unit**	**Meaning**
INFCALC	1/h (AC/h)	Air exchange rate due to infiltration.

4 MapUCE architectural and behavioural archetypes

4.1 Methodology

It is virtually impossible that a TEB user possesses maps of all architectural characteristics of buildings (e.g. the material used for the structural wall, the glazing ratio, and so on). Instead, a user might at least know, for the domain of investigation, the spatial distribution of crucial elements of the urban tissue like the building type (e.g. low-rise, mid-rise, high-rise, activity building, …), the building use (e.g. residential or office) and the building construction period (e.g. built heritage, recent construction, …). We assume that building architecture is mainly shaped by these input parameters and geographical location and provide a full description of the building architecture for each plausible combination of input parameters. The methodology is further described in Tornay et al. (2017). The architectural database of Tornay et al. (2017) contains up to three building archetype for each plausible combination of input parameters. At this stage, we use only the most frequent archetype. The architectural database is available for France, an extension to other countries is planned.

Parameters related to human behaviour (e.g. internal heat release due to electrical appliances, heating and air conditioning of buildings) strongly depend on building use (e.g. residential or office). We therefore assume that these parameters can be assigned as a function of the building use.

4.2 Identifiers describing the urban tissue

The building type, use, construction period and location (territory) are described via identifiers, which are defined in the **MapUCE_Definitions_Final** table. These identifiers can be specified in **NAM_DATA_TEB** as uniform values or maps. The names of the .csv files containing the data on building archetypes and physical parameters (**CCSVFILEARCHI**) and behavioural characteristics (**CCSVFILECOMPO**) can also be specified in **NAM_DATA_TEB**. The definition of all identifiers is given in the tables below.

Remark 1 : CCSVFILEARCHI combines the tables MapUCE_Definitions_Final (definition of identifiers), MapUCE_Architecture_Final (description of building archetypes) and MapUCE_Materials_Final (definition of physical characteristics of materials).

Remark 2 : At the moment only the most frequent building archetype (first entry) in the MapUCE_Architecture_Final table is used.

Entries in NAM_DATA_TEB related to building archetypes.

Type	**Name**	**Default**	**Meaning**
CHARACTER	CCSVFILEARCHI	None	CSV-file containing information on architectural characteristics of building archetypes
CHARACTER	CCSVFILECOMPO	None	CSV-file containing information on human

			behaviours as a function of building use
INTEGER	NUNIF_BLDTYPE	None	Identifier for building type.
CHARACTER	CFNAM_BLDTYPE	‘ ’	
CHARACTER	CFTYP_BLDTYPE	‘ ’	
INTEGER	NUNIF_USE	None	Identifier for building use.
CHARACTER	CFNAM_USE	‘ ’	
CHARACTER	CFTYP_USE	‘ ’	
INTEGER	NUNIF_IND_BLD_AGE	None	Identifier for construction period of buildings with individual housing use
CHARACTER	CFNAM_IND_BLD_AGE	‘ ’	
CHARACTER	CFTYP_IND_BLD_AGE	‘ ’	
INTEGER	NUNIF_COL_BLD_AGE	None	Identifier for construction period of buildings with collective housing use
CHARACTER	CFNAM_COL_BLD_AGE	‘ ’	
CHARACTER	CFTYP_COL_BLD_AGE	‘ ’	
INTEGER	NUNIF_P1TERRITORY	None	Identifier for construction material of historical buildings (before 1948)
CHARACTER	CFNAM_P1TERRITORY	‘ ’	
CHARACTER	CFTYP_P1TERRITORY	‘ ’	
INTEGER	NUNIF_PXTERRITORY	None	Identifier for construction material of recent buildings (after 1948)
CHARACTER	CFNAM_PXTERRITORY	‘ ’	
CHARACTER	CFTYP_PXTERRITORY	‘ ’	

Identifier of building type (typologies d’îlots).

Identifier	Name	Short name
1	Pavillon Discontinu	PD
2	Pavillon Semi-Continu	PSC
3	Pavillon Continu Ilot Ouvert	PCIO
4	Pavillon Continu Ilot Fermé	PCIF
5	Immeuble Discontinu	ID
6	Immeuble Continu, Ilot Ouvert	ICIO
7	Immeuble Continu, Ilot Fermé	ICIF
8	Bâtiment de Grande Hauteur	BGH

9	Bâtiment d’Activité	BA
10	Local	LOCAL

Identifier of building construction period (périodes de construction)

Identifier	**Time interval**	**Short name**
1	<=1948	P1
2	1948-1973	P2
3	1974-1981	P3
4	1982-1989	P4
5	1990-2000	P5
6	2001-2012	P6
7	≥ 2013	P7

Identifier of building use (Usages)

Identifier	**Building use**	**Name**
1	Agriculture	BATIMENT AGRICOLE
2	Castle	CHATEAU
3	Commerce	COMMERCE
4	Collective housing	HABITAT COLLECTIF
5	Individual housing	HABITAT INDIVIDUEL
6	Industrial	BATIMENT INDUSTRIEL
7	Non heated	LOCAL NON CHAUFFE
8	Religious	BATIMENT RELIGIEUX
9	Public health	BATIMENT DE SANTE
10	Educational	BATIMENT ENSEIGNEMENT
11	Greenhouse	SERRE AGRICOLE
12	Sports facility	BATIMENT SPORTIF
13	Office	TERTIAIRE

Identifier of construction material regions (territoires)

The P1 territory describes the dominant construction materials for historical buildings (construction period P1). For P1, there is a large variety of materials used for the walls (stones, brick, wood). The PX territory describes the dominant construction material for the more recent buildings (P2 to P7). For these periods, the construction materials are less variable in space and concrete, steel and glass become the most used materials for the walls. However there are still some spatial differences, especially for the roof covering material.

The identifiers 1 to 3 are related to the PX territory. The territory names are in the format FRANCE_RoofCoveringMaterial.

The identifiers 4 to 19 are related to the P1 territory. The territory names are in the format FRANCE_MaterialClass_WallMainMaterial_RoofCoveringMaterial.

Identifier	Name
1	FRANCE
2	FRANCE_BRIQUE
3	FRANCE_PIERRE
4	FRANCE_PIERRE_CALCAIRE_TUILE
5	FRANCE_PIERRE_CALCAIRE_ARDOISE
6	FRANCE_PIERRE_CALCAIRE_ZINC
7	FRANCE_PIERRE_GRES_TUILE
8	FRANCE_PIERRE_GRES_ARDOISE
9	FRANCE_PIERRE_GRANITE_TUILE
10	FRANCE_PIERRE_GRANITE_ARDOISE
11	FRANCE_PIERRE_GALET_TUILE
12	FRANCE_PIERRE_MEULIERE_TUILE
13	FRANCE_PIERRE_SCHISTE_TUILE
14	FRANCE_PIERRE_GNEISS_TUILE
15	FRANCE_PIERRE_VOLCANIQUE_ARDOISE
16	FRANCE_BOIS_TUILE
17	FRANCE_BOIS_ARDOISE
18	FRANCE_TERRE_TUILE
19	FRANCE_BRIQUE_TUILE

4.3 Parameters that can be initialised via CCSVFILEARCHI

The following parameters can be initialised via the MApUCE architectural tables (CCSVFILEARCHI). Most of these parameters did already exist in previous versions of TEB. In the case one of these parameters is specified via the namelist (XUNIF_…), this entry is prioritised with respect to the entries in the architectural tables. Care is therefore needed during namelist construction.

- Road properties (ALB_ROAD; EMIS_ROAD; HC_ROAD; TC_ROAD; D_ROAD)
- Roof properties (ALB_ROOF; EMIS_ROOF; HC_ROOF; TC_ROOF; D_ROOF)
- Wall properties (ALB_WALL; EMIS_WALL; HC_WALL; TC_WALL; D_WALL)
- Ground floor properties (HC_FLOOR; TC_FLOOR; D_FLOOR)
- Thermal mass properties (HC_MASS; TC_MASS; D_MASS)
- Flag for presence of internal mass (ISMASS)
- Window properties (GR; U_WIN; SHGC; SHGC_SH
- Solar panel properties (ALB_PANEL; EMIS_PANEL; EFF_PANEL; FRAC_PANEL)
- Airtightness (N50)
- Flag for presence of shading elements (SHADEARCHI)

- Flag for presence of mechanical ventilation (ISMECH)
- Air exchange rate due to mechanical ventilation (MECHRATE)
- Fraction of green roofs (GREENROOF)

Remark: In the case where ISMASS=0, the floor height is set equal to the building height, no internal mass will then be considered.

4.4 Parameters that can be initialised via CCSVFILECOMPO

The following parameters can be initialised via the MApUCE behavioural table (CCSVFILECOMPO). If one of these parameters is specified via the namelist (XUNIF_…), this entry is prioritised with respect to the entries in the behavioural table. Care is therefore needed during namelist construction. The detailed definition of these parameters is given in Section 5.

- Schedules of building occupation (DAYWBEG_SCHED ; HOURBEG_SCHED)
- Probability of building occupation (PROBOCC)
- Holiday periods (BEG_HOLIDAY ; END_HOLIDAY ; MOD_HOLIDAY)
- Design temperature for heating (THEAT_…)
- Design temperature and relative humidity for air conditioning (TCOOL_ ; HR_TARGET)
- Fraction of evaporative air conditioning systems (F_WATER_COND)
- Fraction of waste heat to the street canyon (F_WASTE_CAN)
- Rated COP of air conditioning system (COP_RAT)
- Internal heat release (QIN ; QIN_FRAD ; QIN_FLAT ; MODQIN_VCD ; MODQIN_VLD ; MODQIN_NIG ; HOTWAT)
- Ventilation (NATVENT ; FVSUM ; FVVAC ; FVNIG ; FOPEN)
- Shading (FSSUM ; FSVAC ; FSNIG ; WIN_SW_MAX)

5 New description of human behaviour related to building energy consumption

5.1 General methodology

Building energy consumption is strongly dependend on building use (e.g. residential or office) and human behaviour (e.g. design temperature for heating and air conditioning). Building use and human behaviour exhibit a strong variety at urban district scale or even at building scale. The main purpose of our enhancement of TEB is to account for a potential variety of building use and human behaviour for one given urban morphology. This variety might be due to different uses and behaviours in buildings that are distinct but located in the same grid point and/or different uses and behaviours in the same building. We assume that building use and human behaviour primarily influence the thermal environment inside the building (e.g. indoor air temperature) and only secondarily the conditions outside the building (e.g. air temperature in street canyon). For this reason, we modify TEB in order to optionally execute the Building Energy Model (BEM) for different settings of the input parameters related to building use and human behaviour. This can be seen as simulating N flats with different behaviours inside one building and/or N separated buildings with different uses and behaviours. The approach is similar to a tile approach with flux aggregation (e.g. using TEB for urban areas and ISBA for rural areas and aggregate fluxes towards the atmosphere), but the tiles here represent different building uses and human behaviours and the fluxes towards the building envelope (wall and roof) and the outdoor air are aggregated.

Human behaviour related variables can now be specified for up to 9 tiles of building use/behaviour, whose number (NBEMCOMP) can be specified in NAM_TEB. The fractions of these tiles (FRACOMP) used for flux aggregation can be specified in NAM_DATA_BEM.
The input parameters controlling human behaviour are related to the

- Schedules of building occupation (DAYWBEG_SCHED; HOURBEG_SCHED; PROBOCC) given in NAM_DATA_BEM. Details in Appendix A1 of Schoetter et al. (2017).
- Holiday periods (BEG_HOLIDAY, END_HOLIDAY, MOD_HOLIDAY in NAM_DATA_BEM). Details in Appendix A1 of Schoetter et al. (2017).
- Design temperature for heating and air conditioning (THEAT_... and TCOOL_…) in NAM_DATA_BEM). Equations in Appendix A2 of Schoetter et al. (2017).
- Internal heat release (QIN...) in NAM_DATA_BEM. Equations in Appendix A3 of Schoetter et al. (2017).
- Shading (FS… in NAM_DATA_BEM). Equations in Appendix A4 of Schoetter et al. (2017).
- Ventilation (FV... in NAM_DATA_BEM). Equations in Appendix A5 of Schoetter et al. (2017).

The input parameters for up to 9 uses/behaviours can be initialised via NAM_DATA_BEM. However, this is time consuming and error prone. For this reason, a pre-defined setup for urban climate simulations in France has been defined. It is based on using the behavioural archetypes defined in CCSVFILECOMPO and indicators on human behaviour related to building energy consumption. This is further described in Section 5.3.

Improvement of district cooling system (DCS_AREA) treatment (Yu Ting)

- A separate map (DCS_AREA) specifies the grid points with DCS.
- The Coefficient of Performance (COP) of the DCS is different from traditional air conditioners.

Its value (COP_DCS) can be specified by the user.

- The DCS_AREA and COP_DCS area can currently be specified as a map, but not as a function of the building type.
- The DCS_AREA area is a switch, there is no fractional DCS_AREA.

5.2 Namelist changes

New entries in NAM_TEB

Type	**Name**	**Default**	**Purpose**
INTEGER	NBEMCOMP	1	Number of tiles for human behaviour in the building energy model
INTEGER	NTIME_CHANGE	0	Number of time shifts during simulation (e.g. between winter time and daylight savings time)

New entries in NAM_DATA_TEB

Type	**Name**	**Default**	**Meaning**
REAL	XUNIF_FRACIHS	None	Fraction of individual housing building use
CHARACTER	CFNAM_FRACIHS	‘ ’	
CHARACTER	CFTYP_FRACIHS	‘ ’	
REAL	XUNIF_FRACCHS	None	Fraction of collective housing building use
CHARACTER	CFNAM_FRACCHS	‘ ’	
CHARACTER	CFTYP_FRACCHS	‘ ’	
REAL	XUNIF_FRACCOM	None	Fraction of commercial building use
CHARACTER	CFNAM_FRACCOM	‘ ’	
CHARACTER	CFTYP_FRACCOM	‘ ’	
REAL	XUNIF_FRACTER	None	Fraction of tertiary building use
CHARACTER	CFNAM_FRACTER	‘ ’	
CHARACTER	CFTYP_FRACTER	‘ ’	
REAL	XUNIF_FRACIND	None	Fraction of industrial building use
CHARACTER	CFNAM_FRACIND	‘ ’	
CHARACTER	CFTYP_FRACIND	‘ ’	

REAL	XUNIF_FRACNHE	None	Fraction of non heated buildings
CHARACTER	CFNAM_FRACNHE	‘ ’	
CHARACTER	CFTYP_FRACNHE	‘ ’	
REAL	XUNIF_FRACPAV	None	Fraction of low-rise building types
CHARACTER	CFNAM_FRACPAV	‘ ’	
CHARACTER	CFTYP_FRACPAV	‘ ’	
REAL	XUNIF_FRACMRI	None	Fraction of mid-rise building types
CHARACTER	CFNAM_FRACMRI	‘ ’	
CHARACTER	CFTYP_FRACMRI	‘ ’	
REAL	XUNIF_FRACHRI	None	Fraction of high-rise building types
CHARACTER	CFNAM_FRACHRI	‘ ’	
CHARACTER	CFTYP_FRACHRI	‘ ’	
REAL	XUNIF_FRACATB	None	Fraction of activity buildings
CHARACTER	CFNAM_FRACATB	‘ ’	
CHARACTER	CFTYP_FRACATB	‘ ’	
REAL	XUNIF_FOEQI_MAIS	None	Fraction of households with high Equipment-Intensity-of-Use, individual housing
CHARACTER	CFNAM_FOEQI_MAIS	‘ ’	
CHARACTER	CFTYP_FOEQI_MAIS	‘ ’	
REAL	XUNIF_FOEQI_APPT	None	Fraction of households with high Equipment-Intensity-of-Use, collective housing
CHARACTER	CFNAM_FOEQI_APPT	‘ ’	
CHARACTER	CFTYP_FOEQI_APPT	‘ ’	
REAL	XUNIF_FAEQI_MAIS	None	Fraction of households with low Equipment-Intensity-of-Use, individual housing
CHARACTER	CFNAM_FAEQI_MAIS	‘ ’	
CHARACTER	CFTYP_FAEQI_MAIS	‘ ’	
REAL	XUNIF_FAEQI_APPT	None	Fraction of households with low Equipment-Intensity-of-Use, collective housing
CHARACTER	CFNAM_FAEQI_APPT	‘ ’	
CHARACTER	CFTYP_FAEQI_APPT	‘ ’	

REAL	XUNIF_CRE_MAIS	None	Fraction of households with high Energy Control Behaviour, individual housing
CHARACTER	CFNAM_CRE_MAIS	‘’	
CHARACTER	CFTYP_CRE_MAIS	‘’	
REAL	XUNIF_CRE_APPT	None	Fraction of households with high Energy Control Behaviour, collective housing
CHARACTER	CFNAM_CRE_APPT	‘’	
CHARACTER	CFTYP_CRE_APPT	‘’	

Remark: The fractions of building types (FRACPAV; FRACMRI; FRACHRI; FRACATB) are not used in the standard version of the code. However they could be used to initialise different tiles (PATCHES) of TEB taking into account for different building types/urban morphologies at grid point scale. This will however require modifications of the source code.

Removed from NAM_DATA_TEB

- NUNIF_BLD_AGE; CFNAM_BLD_AGE; CFTYP_BLD_AGE. Replaced by the individual (IND_BLD_AGE) and collective (COL_BLD_AGE) housing construction periods.
- CCSVDATAFILE. Splitted into the architecture (CCSVFILEARCHI) and behaviour (CCSVFILECOMPO) files.

New entries in NAM_DATA_BEM

Type	Name	Default	Meaning
REAL (NBEMCOMP_MAX=9)	XUNIF_FRACOMP	1	Fractions of up to 9 tiles of building use/human behaviour. The sum of the fractions must equal 1.
CHARACTER	CFNAM_FRACOMP		
CHARACTER	CFTYP_FRACOMP		
REAL (NBEMCOMP_MAX=9)	XUNIF_NATVENT	0 (No ventilation)	Control variable for ventilation for up to 9 behaviours in building 0 : No ventilation 1 : Manual ventilation 2 : Automatic ventilation
CHARACTER	CFNAM_NATVENT		
CHARACTER	CFTYP_NATVENT		
REAL	XUNIF_RESIDENTIAL	1.0	Residential fraction (only used for solar panels) [1].
CHARACTER	CFNAM_RESIDENTIAL		
CHARACTER	CFTYP_RESIDENTIAL		

REAL	XUNIF_ISMECH	0.0	Presence of mechanical ventilation (1=YES ; 0 = NO).
CHARACTER	CFNAM_ISMECH		
CHARACTER	CFTYP_ISMECH		
REAL	XUNIF_MECHRATE	0.0	Air exchange due to mecanical ventilation [vol./h].
CHARACTER	CFNAM_MECHRATE		
CHARACTER	CFTYP_MECHRATE		
REAL	XUNIF_SHADEARCHI	0.0	Presence of shading devices. 0 : No shading devices 1 : Adjustable shading devices 2 : Permanent shading devices
CHARACTER	CFNAM_SHADEARCHI		
CHARACTER	CFTYP_SHADEARCHI		
REAL	XUNIF_TDESV	295.16	Indoor air temperature, people or automatic ventilation try to achieve by opening/closing of windows [K].
CHARACTER	CFNAM_TDESV		
CHARACTER	CFTYP_TDESV		
REAL	XUNIF_WIN_SW_MAX	150.0	Threshold for shortwave radiation received by walls used for shading calculations [W/m²].
CHARACTER	CFNAM_WIN_SW_MAX		
CHARACTER	CFTYP_WIN_SW_MAX		
REAL	XUNIF_FOPEN	0.0	Maximum fraction of windows opened in case ventilation is made [1].
CHARACTER	CFNAM_FOPEN		
CHARACTER	CFTYP_FOPEN		
REAL (NBEMCOMP_MAX= 9)	XUNIF_TCOOL_OCCD	300.16	Design temperature for air conditioning when the building is occupied (OCC) during the day (D) [K]. This value can be specified for up to 9

			tiles of use/behaviour.
CHARACTER	CFNAM_TCOOL_OCCD		
CHARACTER	CFTYP_TCOOL_OCCD		
REAL (NBEMCOMP_MAX= 9)	XUNIF_TCOOL_OCCN	300.16	Design temperature for air conditioning when the building is occupied (OCC) during the night (N) [K]. This value can be specified for up to 9 tiles of use/behaviour.
CHARACTER	CFNAM_TCOOL_OCCN		
CHARACTER	CFTYP_TCOOL_OCCN		
REAL (NBEMCOMP_MAX= 9)	XUNIF_TCOOL_VCDD	300.16	Design temperature for air conditioning when the building is vacant (VC) During the Day (DD) [K]. This value can be specified for up to 9 tiles of use/behaviour.
CHARACTER	CFNAM_TCOOL_VCDD		
CHARACTER	CFTYP_TCOOL_VCDD		
REAL (NBEMCOMP_MAX= 9)	XUNIF_TCOOL_VCDN	300.16	Design temperature for air conditioning when the building is vacant (VC) During the Night (DN) [K]. This value can be specified for up to 9 tiles of use/behaviour.
CHARACTER	CFNAM_TCOOL_VCDN		
CHARACTER	CFTYP_TCOOL_VCDN		
REAL (NBEMCOMP_MAX= 9)	XUNIF_TCOOL_VCLD	300.16	Design temperature for air conditioning when the building is vacant (VC) for Long Duration (LD) [K]. Example : holiday home. This value can be specified for up to 9 tiles of use/behaviour.
CHARACTER	CFNAM_TCOOL_VCLD		
CHARACTER	CFTYP_TCOOL_VCLD		
REAL (NBEMCOMP_MAX= 9)	XUNIF_THEAT_OCCD	293.16	Design temperature for heating when the building is occupied (OCC) during the day

			(D) [K]. This value can be specified for up to 9 tiles of use/behaviour.
CHARACTER	CFNAM_THEAT_OCCD		
CHARACTER	CFTYP_THEAT_OCCD		
REAL (NBEMCOMP_MAX=9)	XUNIF_THEAT_OCCN	293.16	Design temperature for heating when the building is occupied (OCC) during the night (N) [K]. This value can be specified for up to 9 tiles of use/behaviour.
CHARACTER	CFNAM_THEAT_OCCN		
CHARACTER	CFTYP_THEAT_OCCN		
REAL (NBEMCOMP_MAX=9)	XUNIF_THEAT_VCDD	293.16	Design temperature for heating when the building is vacant (VC) During the Day (DD) [K]. This value can be specified for up to 9 tiles of use/behaviour.
CHARACTER	CFNAM_THEAT_VCDD		
CHARACTER	CFTYP_THEAT_VCDD		
REAL (NBEMCOMP_MAX=9)	XUNIF_THEAT_VCDN	293.16	Design temperature for heating when the building is vacant (VC) During the Night (DN) [K]. This value can be specified for up to 9 tiles of use/behaviour.
CHARACTER	CFNAM_THEAT_VCDN		
CHARACTER	CFTYP_THEAT_VCDN		
REAL (NBEMCOMP_MAX=9)	XUNIF_THEAT_VCLD	293.16	Design temperature for heating when the building is vacant (VC) for Long Duration (LD) [K]. Example : holiday home. This value can be specified for up to 9 tiles of use/behaviour.
CHARACTER	CFNAM_THEAT_VCLD		
CHARACTER	CFTYP_THEAT_VCLD		
REAL (NBEMCOMP_MAX=	XUNIF_QIN	5.8	Internal heat release [W/m²(floor)]. This value

9)			can be specified for up to 9 tiles of use/behaviour.
CHARACTER	CFNAM_QIN		
CHARACTER	CFTYP_QIN		
REAL (NBEMCOMP_MAX=9)	XUNIF_MODQIN_VCD	1.0	Modulation factor for internal heat release when the building is vacant for short duration [1]. This value can be specified for up to 9 tiles of use/behaviour.
CHARACTER	CFNAM_MODQIN_VCD		
CHARACTER	CFTYP_MODQIN_VCD		
REAL (NBEMCOMP_MAX=9)	XUNIF_MODQIN_VLD	1.0	Modulation factor for internal heat release when the building is vacant for long duration (e.g. holiday home) [1]. This value can be specified for up to 9 tiles of use/behaviour.
CHARACTER	CFNAM_MODQIN_VLD		
CHARACTER	CFTYP_MODQIN_VLD		
REAL (NBEMCOMP_MAX=9)	XUNIF_MODQIN_NIG	1.0	Modulation factor for internal heat release during the night [1]. This value can now be specified for up to 9 tiles of use/behaviour.
CHARACTER	CFNAM_MODQIN_NIG		
CHARACTER	CFTYP_MODQIN_NIG		
REAL (NBEMCOMP_MAX=9)	XUNIF_FVSUM	0.0	Fraction of households using natural ventilation during summer (warm conditions) [1]. This value can be specified for up to 9 tiles of use/behaviour.
CHARACTER	CFNAM_FVSUM		
CHARACTER	CFTYP_FVSUM		
REAL (NBEMCOMP_MAX=9)	XUNIF_FVVAC	0.0	Fraction of households using natural ventilation when the building is vacant [1]. This value can

			be specified for up to 9 tiles of use/behaviour.
CHARACTER	CFNAM_FVVAC		
CHARACTER	CFTYP_FVVAC		
REAL (NBEMCOMP_MAX=9)	XUNIF_FVNIG	0.0	Fraction of households using natural ventilation during the night [1]. This value can be specified for up to 9 tiles of use/behaviour.
CHARACTER	CFNAM_FVNIG		
CHARACTER	CFTYP_FVNIG		
REAL (NBEMCOMP_MAX=9)	XUNIF_FSSUM	0.0	Fraction of households closing shading elements during summer (warm conditions) [1]. This value can be specified for up to 9 tiles of use/behaviour.
CHARACTER	CFNAM_FSSUM		
CHARACTER	CFTYP_FSSUM		
REAL (NBEMCOMP_MAX=9)	XUNIF_FSVAC	0.0	Fraction of households closing shading elements when the building is vacant [1]. This value can be specified for up to 9 tiles of use/behaviour.
CHARACTER	CFNAM_FSVAC		
CHARACTER	CFTYP_FSVAC		
REAL (NBEMCOMP_MAX=9)	XUNIF_FSNIG	0.0	Fraction of households closing shading elements during the night [1]. This value can be specified for up to 9 tiles of use/behaviour.
CHARACTER	CFNAM_FSNIG		
CHARACTER	CFTYP_FSNIG		
REAL (3, NBEMCOMP_MAX=9)	XUNIF_DAYWBEG_SCHED	/1; 6; 7/	Day of the week for schedules on human behaviour. [1=Monday ; 7 = Saturday]. 3 periods can be specified (usually Monday to Friday ; Saturday ; Sunday) for up

			to 9 tiles of human behaviour.
CHARACTER	CFNAM_DAYWBEG_SCHED		
CHARACTER	CFTYP_DAYWBEG_SCHED		
REAL (3x4, NBEMCOMP_MAX=9)	XUNIF_HOURBEG_SCHED	/5; 7; 16; 23/	Hour of the day [solar time] for schedules of human behaviour. For each of the 3 day-of-week periods, 4 periods can be specified (e.g. 6 h to 8 h; 8 h to 18 h; 18 h to 22 h; 22 h to 6 h). The last entry defines the 'night' period.
CHARACTER	CFNAM_HOURBEG_SCHED		
CHARACTER	CFTYP_HOURBEG_SCHED		
REAL (3x4, NBEMCOMP_MAX=9)	XUNIF_PROBOCC	1.0	Probability that the building is occupied for the schedules defined by DAYWBEG_SCHED and HOURBEG_SCHED
CHARACTER	CFNAM_PROBOCC		
CHARACTER	CFTYP_PROBOCC		
REAL (1,NBEMCOMP_MAX=9)	XUNIF_BEG_HOLIDAY	400.0	Julian day of year of the beginning of holiday period. One holiday period can be specified for up to 9 tiles for human behaviour.
CHARACTER	CFNAM_BEG_HOLIDAY		
CHARACTER	CFTYP_BEG_HOLIDAY		
REAL (1,NBEMCOMP_MAX=9)	XUNIF_END_HOLIDAY	400.0	Julian day of year of the end of holiday period. One holiday period can be specified for up to 9 tiles for human behaviour.
CHARACTER	CFNAM_END_HOLIDAY		
CHARACTER	CFTYP_END_HOLIDAY		
REAL	XUNIF_MOD_HOLIDAY	1.0	Modulation factor for

(NBEMCOMP_MAX=9)			internal heat release during holiday period [1].
CHARACTER	CFNAM_MOD_HOLIDAY		
CHARACTER	CFTYP_MOD_HOLIDAY		
REAL	XUNIF_DCS_AREA	1.0E+20	presence of district cooling system [1]
CHARACTER	CFNAM_DCS_AREA		Name file
CHARACTER	CFTYP_DCS_AREA		Type file
REAL	XUNIF_COP_DCS	1.0E+20	Rated COP of the district cooling system [1]
CHARACTER	CFNAM_COP_DCS		Name file
CHARACTER	CFTYP_COP_DCS		Type file

Removed from NAM_TEBn
XDT_RES and XDT_OFF. Now the absolute values of the design temperature for heating and air conditioning for occupied/vacant and day/night can be specified via the namelist.

Removed from NAM_DATA_BEM

- XUNIF_TCOOL_TARGET; CFNAM_TCOOL_TARGET; CFTYP_TCOOL_TARGET; XUNIF_THEAT_TARGET; CFNAM_THEAT_TARGET; CFTYP_THEAT_TARGET. These variables are replaced by the more detailed design temperature (e.g. Occupied-day, ...)
- XUNIF_EFF_HEAT. Now the efficiency per type of heating combustible is specified in modd_bem_optionn.
- XUNIF_V_VENT : replaced by MECHRATE.

Remark : The values specified for long term vacancy (heating/cooling design temperature, modulation of internal heat release) are not used at the moment. They might be used in the case an information on holiday home density, and so on, would be available. However, a modification of the source code would be required.

5.3 Human behaviours for TEB applications in France

For applications of TEB in France, a predefined description of human behaviours is available (Section 3 of Schoetter et al., 2017). It relies on building use and indicators describing human behaviours that have been developed by Bourgeois et al. (2017). They developed statistical models linking human behaviours obtained from the ENERGIHAB survey (Lévy and Roudil, 2012) with the French census (RP2011). Since the French census is available for the entire population, it is possible to obtain maps of these indicators for entire France. The statistical models are applied to the census data to obtain the behavioural class of each household. As a result it is known for each household whether it belongs to :

- **The High or Low ECR class**. ECR is the Energy Control Behavior and describes the behaviour with regard to energy consumption (turning heaters off when windows are open or rooms unoccupied, lowering thermostat temperatures, etc.).
- **The High, Medium or Low EQI class.** EQI is the Equipment-Intensity-of-Use indicator and is obtained by combining the EQuipment Indicator (EQ ; Ownership of large household

appliances) and the Intensity of Use Indicator (IU) which describes the intensity of use of large household appliances. For the Equipment-Intensity-of-Use (EQI) indicator the 3 class version is taken (strong, intermediate or weak). The attribution is the following:

- High EQ & High IU -> High EQI
- Low EQ & High IU -> Medium EQI
- High EQ & Low IU -> Medium EQI
- Low EQ & Low IU -> Low EQI.

The results of the statistical model of Bourgeois et al. (2017) that are available for each household are mapped and can be read by TEB (NAM_DATA_TEB). The additional maps are :

- **CRE_MAIS**: Fraction of households with high ECR, individual housing
- **CRE_APPT**: Fraction of households with high ECR, collective housing
- **FOEQI_MAIS**: Fraction of households with high EQI, individual housing
- **FOEQI_APPT**: Fraction of households with high EQI, collective housing
- **FAEQI_MAIS**: Fraction of households with low EQI, individual housing
- **FAEQI_APPT**: Fraction of households with low EQI, collective housing

The fraction of low ECR and medium EQI is the complement of the fraction of high ECR and High/Low EQI.

Two levels of detail can be used for representation of human behaviour in France :

- **Configuration A : Main building use/behaviour at grid point scale**
- **Configuration B : 6 tiles of building use/behaviour at grid point scale**

Configuration A corresponds to DOM in Section 4.2.3 (Figure 6b) in Schoetter et al. (2017).
Configuration B corresponds to MAP in Section 4.2.3 (Figure 6d) in Schoetter et al. (2017).

Configuration A : Main use/behaviour at grid point scale (NBEMCOMP=1 in NAM_TEB)

This configuration can be used by specifying NBEMCOMP=1 in NAM_TEB and the CSV file describing human behaviours (CCSVFILECOMPO) in NAM_DATA_TEB. For this setup, the dominant building use at grid point scale is taken, and all input parameters related to human behaviour are specified as a function of the dominant building use. The behavioural parameters in CCSVFILECOMPO are described in Schoetter et al. (2017) :

- Table A1: Schedules for building occupation
- Table A2: Fractional building occupation
- Table A3: Design temperature for heating and air conditioning
- Table A4: Internal heat release
- Table A5: Shading and ventilation

The values for the heating design temperature in residential buildings given in Table A2 are averaged for High and Low ECR. For the internal heat release (Table A3), the values for medium EQI are taken.

Configuration B : 6 tiles of building use/behaviour at grid point scale (NBEMCOMP=6 in NAM_TEB)

This configuration can be used by specifying NBEMCOMP=6 in NAM_TEB and the CSV file describing human behaviours (CCSVFILECOMPO) in NAM_DATA_TEB. For this setup, up to 6 tiles of building use/behaviours at grid point scale are taken into account. The description of fractional use/behaviour is made as a function of the dominant use, which determines building architecture (Table 1 in Schoetter et al. (2017)).

- **Residential use** : 6 tiles of use/behaviours are considered. A non-heated fraction (initialised via Table A3 and maps of FRACNHE), a commercial and office fraction (initialised via maps of FRACCOM and FRACTER), and three different values for the heating design temperature (the values for high and low ET in Table A3 of Schoetter et al. (2017) and their arithmetic average). The fractions for tiles with different heating design temperature are initialised via the the maps of the ECR indicator (Equations 28 to 30 in Schoetter et al. (2017), the conditional probabilities are given in Table A6 of Schoetter et al. (2017).
- **Office use** : 4 tiles with a non-heated fraction and three design temperatures for heating and air conditioning
- **Commerce use** : 4 tiles with a non-heated fraction and three design temperatures for heating and air conditioning
- **Educational use** : 4 tiles with a non-heated fraction and three design temperatures for heating. There is no air conditioning.
- **Public health** : 4 tiles with a non-heated fraction and three design temperatures for heating and air conditioning
- **Industrial use** : 2 tiles (heated and non-heated part)
- **Agriculture, religious, sport, castle, non-heated** : Only 1 tile with main use considered

The maps of EQI (FOEQI and FAEQI) are not used to further distinguish fractional building use/behaviour, since the absolute magnitude of the internal heat release is not sufficient to justify a more detailed description for urban climate modelling. Therefore, the maps of EQI are used to modulate QIN (Equation 31 in Schoetter et al., 2017), but the same value is applied for all tiles with residential use.

5.4 Output variables

The new version includes more detailed diagnostics on energy consumption and human behaviours like shading and ventilation. Furthermore, the unit of all energy consumption variables is now W/m²(urban).

Name	**Unit**	**Meaning**
TBLD	K	Soil temperature under buildings for layer
PSOLD	Pa	Pressure at previous time step
H_TRAACT	W/m²(urban)	Actual (modulated) sensible heat flux due to traffic
LE_TRAACT	W/m²(urban)	Actual (modulated) latent heat flux due to traffic
H_INDACT	W/m²(urban)	Actual (modulated) sensible heat flux due to industry
LE_INDACT	W/m²(urban)	Actual (modulated) latent heat flux due to industry
QF_BLT	W/m²(bld+road)	Built surface anthropogenic heat flux
QF_RD	W/m²(road)	Road surface anthropogenic heat flux
QF_RF	W/m²(roof)	Roof surface anthropogenic heat flux
QF_WL	W/m²(facade)	Facade surface anthropogenic heat flux
QF_WLA	W/m²(facade)	Wall A anthropogenic heat flux

QF_WLB	W/m²(facade)	Wall B anthropogenic heat flux
DIR_SW_WLA	W/m²(facade)	Dir Sdown received by wall A
DIR_SW_WLB	W/m²(facade)	Dir Sdown received by wall B
SCA_SW_WL	W/m²(facade)	Scattered Sdown received by wall
SWU_RF	W/m² (roof)	Sdown reflected by roofs
LWU_RF	W/m² (roof)	Ldown emitted by roofs
SWU_CAN	W/m² (urban)	Sdown reflected by the canyon
LWU_CAN	W/m² (urban)	Ldown reflected by the canyon
DIR_SW_RD	W/m² (road)	Direct Sdown received by roads
SCA_SW_RD	W/m² (road)	Scattered Sdown received by roads
QSNOW_RD	W/m²(road)	Heat storage due to snow coverage on road
QSNOW_RF	W/m²(roof)	Heat storage due to snow coverage on roof
H_WASTE_CANY	W/m²(urban)	Sensible waste heat to street canyon
LE_WASTE_CANY	W/m²(urban)	Latent waste heat to street canyon
H_WASTE_ROOF	W/m²(urban)	Sensible waste heat to air above roof
LE_WASTE_ROOF	W/m²(urban)	Latent waste heat to air above roof
LE_EVAP_COOL	W/m²(urban)	Latent waste heat due to evaporative cooling
SENFABSTOR	W/m²(urban)	Sensible heat stored in urban fabric
LATFABSTOR	W/m²(urban)	Latent heat stored in urban fabric
HVAC_HT	W/m²(urban)	Heating energy consumption aggregated over all tiles of building use/ behaviour. CAUTION : Unit changed from W/m²(bld) to W/m²(urban).
HVAC_CL	W/m²(urban)	Cooling energy consumption aggregated over all tiles of building use/ behaviour. CAUTION : Unit changed from W/m²(bld) to W/m²(urban)
HVAC_HT_{ntile}	W/m²(urban)	Heating energy consumption for tile.
HVAC_CL_{ntile}	W/m²(urban)	Cooling energy consumption for tile.
VENTNIG_{ncomp}	-	Switch for ventilation during night
SHADVAC_{ncomp}	-	Switch for shading during vacancy
QINACT	W/m²(urban)	Actual internal heat release aggregated over all tiles of building use/ behaviour. CAUTION : Unit changed from W/m²(bld) to W/m²(urban)
QINACT_{tile}	W/m²(urban)	Actual internal heat release per tile of building use/behaviour.
QINACTLAT	W/m²(urban)	Actual internal energy release (latent)
QINACTSEN	W/m² (urban)	Actual internal energy release (sensible)
QINHOTW	W/m²(urban)	Energy consumption for domestic warm water aggregated over all tiles of building use/ behaviour.

HOTWAT_{ntile}	W/m²(urban)	Energy consumption for domestic warm water per tile of building use/behaviour.
HOTWAT_GAS	W/m²(urban)	Actual gas energy consumption for domestic warm water aggregated over all tiles of building use/ behaviour.
HOTWAT_ELEC	W/m²(urban)	Actual electrical energy consumption for domestic warm water aggregated over all tiles of building use/ behaviour.
HVAC_HT_ELEC	W/m²(urban)	Electrical energy consumed for heating.
HVAC_HT_GAS	W/m²(urban)	Gas energy consumed for heating.
HVAC_HT_FUEL	W/m²(urban)	Fuel energy consumed for heating.
HVAC_HT_OTHER	W/m²(urban)	Other energy sources consumed for heating.
INFCALC	Vol/h	Calculated infiltration rate
BLDOCC{tile}	1	Fraction of building occupation per tile of building use/behaviour.
DIAGSHAD{tile}	1	Fraction of shading elements closed per tile of building use/behaviour.
DIAGVENT{tile}	1	Fraction of households opening windows per tile of building use/behaviour. This value does not correspond to the fraction of windows opened, since it is assumed that only a part of the windows is opened (FOPEN).
DIAGVEFL{tile}	1/h	Air exhange rate due to ventilation per tile of building use/behaviour.
QIN_KWH	kWh/m²(floor)/y	Internal heat release aggregated over all tiles of building use/behaviour.
HVAC_HT_KWH	kWh/m²(floor)/y	Heating energy demand aggregated over all tiles of building use/behaviour.
HVAC_CL_KWH	kWh/m²(floor)/y	Cooling energy demand aggregated over all tiles of building use/behaviour.
HVACC_CL	J/m²(urban)	Cumulated cooling energy consumption. Caution : Unit changed from J/m²(bld) to J/m²(urban)
HVACC_HT	J/m²(urban)	Cumulated heating energy consumption. Caution : Unit changed from J/m²(bld) to J/m²(urban)
QINACTCUM	J/m²(urban)	Cumulated internal heat release.
HVACC_HT_ELEC	J/m²(urban)	Cumulated electrical heating energy consumption.
HVACC_HT_GAS	J/m²(urban)	Cumulated gas heating energy consumption.
HVACC_HT_FUEL	J/m²(urban)	Cumulated fuel heating energy consumption.
HVACC_HT_OTHER	J/m²(urban)	Cumulated heating energy consumption, other combustibles
HOTWATC	J/m²(urban)	Cumulated energy consumption for domestic warm water

HOTWATC_GAS	J/m²(urban)	Cumulated gas energy consumption for domestic warm water
HOTWATC_ELEC	J/m²(urban)	Cumulated electrical energy consumption for domestic warm water
U_LOWCAN	m/s	Wind speed in lowest level of street canyon
ROAD_SHADE	1	Fraction of street canyon in shade
ROOFTK	m	Total roof thickness
WALLTK	m	Total wall thickness
MASSTK	m	Total mass thickness
TS_SP	K	Surface temperature of solar panels on roofs

6 Modelling of CO_2 fluxes in urban areas

6.1 Methodology

Four sources and/or sinks of CO_2 in urban areas are considered, details are given in Goret et al. (in preparation)

- **Buildings (heating and domestic warm water)**
- **Traffic**
- **Human metabolism**
- **Urban vegetation**

The building-related CO_2 flux is calculated using the heating energy demand calculated by the building energy model (BEM) included in TEB as a function of the prevailing meteorological conditions, the characteristics of the building envelope and human behaviour. The emission of CO_2 as a function of the heating energy demand strongly depends on the combustible of the heating system. For this reason, the fraction of the heating system combustibles (electricity, gas, fuel and others) can now be specified in NAM_DATA_BEM. The emission factors (e.g. CF_CO2_GAS; kg of CO_2 released per J of gas energy consumption) can also be specified in NAM_DATA_BEM. Furthermore, the total energy demand for domestic warm water and the fraction of warm water heated by gas (causing CO_2 emissions) can be specified. The remaining fraction of warm water is assumed to be heated by electricity.

The traffic-related CO_2 flux (SFCO2_RD) is not a prognostic variable of TEB, but is directly specified in the namelist (NAM_DATA_TEB). This value represents the temporal average CO_2 flux, which can be modulated by month of year (TRAF_MONTHLY), day of week (TRAF_DAILY) and hour of day (TRAF_HOURLY).

The CO_2 flux due to human metabolism is calculated based on a constant population density (NB_POP), which can be specified in NAM_DATA_TEB. Temporal variations of the distribution of inhabitants, workers and visitors inside the city are not taken into account.

The CO_2 flux due to urban vegetation is calculated with the SVAT model ISBA. The ecosystem respiration parameter RE25 specific to urban vegetation can now be entered via NAM_DATA_TEB_GARDEN.

6.2 Namelist modifications

New entries in NAM_DATA_TEB

Type	Name	Default	Purpose
REAL	XUNIF_NB_POP	0.0	Population density [1/km²]
CHARACTER	CFNAM_NB_POP	‘ ’	
CHARACTER	CFTYP_NB_POP	‘ ’	
REAL	XUNIF_SFCO2_RD	0.0	CO_2 flux due to trafic

			[kg/s/m²(urban)]
CHARACTER	CFNAM_SFCO2_RD	‘ ’	
CHARACTER	CFTYP_SFCO2_RD	‘ ’	
REAL (NTIME_CHANGE +1)	XUNIF_DELTA_LEGAL_TIME	Solar time is used to modulate trafic fluxes	Difference between UTC and legal time [h]
CHARACTER	CFNAM_DELTA_LEGAL_TIME	‘ ’	
CHARACTER	CFTYP_DELTA_LEGAL_TIME	‘ ’	
REAL (4, NTIME_CHANGE)	XUNIF_TIME_OF_CHANGE	NONE	Date of change of legal time (year, month, day, second)
REAL (12)	XPAR_TRAF_MONTHLY	1.0	Modulation factor for trafic heat flux by month of year (January to December)
REAL (7)	XPAR_TRAF_DAILY	/ 1.05; 1.07; 1.08; 1.09; 1.15; 0.86; 0.7 /	Modulation factor for traffic heat flux by day of week (Monday to Sunday)
REAL (24)	XPAR_TRAF_HOURLY	12/33 between 0 h and 6 h and between 21 h and 0 h. 48/33 else.	Modulation factor for traffic heat flux by hour of day (0 h to 23 h)

New entries in NAM_DATA_BEM

Type	Name	Default	Meaning
REAL	XUNIF_FRAC_HEAT_ELEC	0.5	Fraction of households with electricity as heating combustible [1]
CHARACTER	CFNAM_FRAC_HEAT_ELEC	‘ ’	
CHARACTER	CFTYP_FRAC_HEAT_ELEC	‘ ’	
REAL	XUNIF_FRAC_HEAT_GAS	0.25	Fraction of households with gas as heating combustible [1]
CHARACTER	CFNAM_FRAC_HEAT_GAS	‘ ’	
CHARACTER	CFTYP_FRAC_HEAT_GAS	‘ ’	
REAL	XUNIF_FRAC_HEAT_FUEL	0.25	Fraction of households with fuel as heating combustible [1]
CHARACTER	CFNAM_FRAC_HEAT_FUEL	‘ ’	

CHARACTER	CFTYP_FRAC_HEAT_FUEL	‘’	
REAL	XUNIF_FRAC_HEAT_OTHER	0.0	Fraction of households with other heating combustibles (e.g. wood) [1]
CHARACTER	CFNAM_FRAC_HEAT_OTHER	‘’	
CHARACTER	CFTYP_FRAC_HEAT_OTHER	‘’	
REAL (NBEMCOMP _MAX=9)	XUNIF_HOTWAT	0.0	Energy consumption for domestic warm water [W/m²(floor)] It can be specified for up to 9 tiles of building use and human behaviour.
CHARACTER	CFNAM_HOTWAT	‘’	
CHARACTER	CFTYP_HOTWAT	‘’	
REAL	XUNIF_F_HW_GAS	0.0	Fraction of domestic warm water heated with gas [1]. The remainder is assumed to be heated with electricity.
CHARACTER	CFNAM_F_HW_GAS	‘’	
CHARACTER	CFTYP_F_HW_GAS	‘’	
REAL	XPAR_CF_CO2_ELEC	0.0	Emission factor [kg(CO_2)/J(elec. heating)
REAL	XPAR_CF_CO2_GAS	5.7E-8	Emission factor [kg(CO_2)/J(gas heating)
REAL	XPAR_CF_CO2_FUEL	7.5E-8	Emission factor [kg(CO_2)/J(fuel heating)
REAL	XPAR_CF_CO2_OTHER	9.2E-8	Emission factor [kg(CO_2)/J(other heating). The default emission factor assumes wood.

New entries in NAM_DATA_TEB_GARDEN

Type	**Name**	**Default**	**Purpose**
REAL	XUNIF_RE25	3.0E-7	Ecosystem Respiration parameter (kg/m²/s)
CHARACTER	CFNAM_RE25	‘ ’	
CHARACTER	CFTYP_RE25	‘ ’	

6.3 New output variables

Name	Meaning	Unit
SFCO2_T_VEG	CO_2 flux density due to urban vegetation	[kg(CO_2)/s/m²(urban)]
SFCO2_T_BLD	CO_2 flux density due to buildings	[kg(CO_2)/s/m²(urban)]
SFCO2_T_RD	CO_2 flux density due to traffic	[kg(CO_2)/s/m²(urban)]
SFCO2_T_POP	CO_2 flux density due to human metabolism	[kg(CO_2)/s/m²(urban)]
SFCO2_T	Total CO_2 flux density	[kg(CO_2)/s/m²(urban)]
GPP_GD	Gross primary production by urban vegetation	[kg(CO_2)/s/m²(urban)]
R_ECO_GD	Ecosystem respiration by urban vegetation	[kg(CO_2)/s/m²(urban)]

Remark 1 : At the moment the CO_2 flux calculated by ISBA (SFCO2_ISBA) has the unit [kg(CO_2)/kg(air) x m/s]. In order to aggregate the values from ISBA and TEB, the (old) output variable SFCO2_TEB [kg(CO_2)/kg(air) x m/s] needs to be taken and NOT SFCO2_T. The new output variables related to CO_2 use the unit [kg(CO_2)/s/m²(urban)], since this is usually the unit of observed CO_2 fluxes.

Remark 2 : All output CO_2 fluxes are defined on the urban tile of SURFEX [kg(CO_2)/s/m²(urban)]. They have to be multiplied with the TOWN fraction to convert them to kg(CO_2)/s/m².

Remark 3 : The CO_2 flux due to urban vegetation is linked with the ecosystem respiration and the gross primary production of urban vegetation.

Changes of code related to CO2 fluxes to be fully consistant with Goret et al. (2019)
Add PPOP_MODULATION similar to PTRAF_MODULATION to allow for the modulation of the CO2 flux due to human metabolism as a function of the month of year, the day of week, and the hour of the day. This is stated in Equation (7) of Goret et al. (2019). Since we have currently no information about the modulation factors for the population density, the modulation factors are set to 1. Furthermore, both the trafic and population modulation factors could become maps.
SFCO2_T_VEG = R_ECO_GD – GPP_GD

7 Time averaged output of near surface and canopy variables

7.1 Methodology

For modelling approaches involving SURFEX coupled to an atmospheric model in Large Eddy Simulation (LES) mode (e.g. MésoNH at 250 m horizontal resolution during a sunny summer day) near surface meteorological variables like the 2 m temperature or 10 m wind speed can be influenced by the atmospheric turbulence. Furthermore, radiation fields can be very heterogenoous for meteorological situations involving cumulus clouds. As a consequence the use of instantanouus output fields can be misleading since they contain a lot of variability caused by boundary layer turbulence and cumulus clouds. For this reason we introduce temporal averages of some crucial near surface variables. The averaging is made during two output time steps (usually half an hour or one hour). Considering a typical time scale of boundary layer turbulence of 5 min. to 10 min, a hourly average consists of 5 to 10 eddies per hour. An averaging window of one hour can therefore considerably reduce the variability due to boundary layer turbulence, but does not represent a rigorous ensemble average (e.g. 100 realisations of a simulation in LES mode).

7.2 New output variables

Name	Meaning	Unit
T2MMEA_TEB	Mean 2 m air temperature in street canyon	[K]
Q2MMEA_TEB	Mean 2 m specific humidity in street canyon	[kg/kg]
HU2MMEA_TEB	Mean 2 m relative humidity in street canyon	[%]
WFF10MM_TEB	Mean 10 m horizontal wind speed in urban canopy layer	[m/s]
WDD10MM_TEB	Mean 10 m horizontal wind direction in urban canopy layer	[degrees from north]
T2MMEA_ISBA	Mean 2 m air temperature in rural area	[K]
Q2MMEA_ISBA	Mean 2 m specific humidity in rural area	[kg/kg]
HU2MMEA_ISBA	Mean 2 m relative humidity in rural area	[%]
WFF10MM_ISBA	Mean 10 m horizontal wind speed in rural area	[m/s]
WDD10MM_ISBA	Mean 10 m horizontal wind direction in rural area	[degrees from north]
T2MMEA_WAT	Mean 2 m air temperature over inland water	[K]
Q2MMEA_WAT	Mean 2 m specific humidity over inland water	[kg/kg]
HU2MMEA_WAT	Mean 2 m relative humidity over inland water	[%]
WFF10MM_WAT	Mean 10 m horizontal wind speed over inland water	[m/s]

WDD10MM_WAT	Mean 10 m horizontal wind direction over inland water	[degrees from north]
T2MMEA_SEA	Mean 2 m air temperature over sea and ocean	[K]
Q2MMEA_SEA	Mean 2 m specific humidity over sea and ocean	[kg/kg]
HU2MMEA_SEA	Mean 2 m relative humidity over sea and ocean	[%]
WFF10MM_SEA	Mean 10 m horizontal wind speed over sea and ocean	[m/s]
WDD10MM_SEA	Mean 10 m horizontal wind direction over sea and ocean	[degrees from north]
TEB_CAN_UM${level}	Mean wind speed at TEB canopy levels	[m/s]
TEB_CAN_TM${level}	Mean temperature at TEB canopy levels	[K]
TEB_CAN_QM${level}	Mean absolute humidity at TEB canopy levels	[kg/m^3]
TEB_CAN_RM${level}	Mean relative humidity at TEB canopy levels	[1]
TEB_CAN_PM${level}	Mean pressure at TEB canopy levels	[Pa]
ISB_CAN_UM${level}	Mean wind speed at ISBA canopy levels	[m/s]
ISB_CAN_TM${level}	Mean temperature at ISBA canopy levels	[K]
ISB_CAN_QM${level}	Mean absolute humidity at ISBA canopy levels	[kg/m^3]
ISB_CAN_RM${level}	Mean relative humidity at ISBA canopy levels	[1]
ISB_CAN_PM${level}	Mean pressure at ISBA canopy levels	[Pa]

Remark 1 : Averages of horizontal wind speed and direction are based on average u and v components.

Remark 2 : Averages of UTCI and TRAD have also been introduced (Section 1).

8 New road description

8.1 Methodology

The code has been adapted so that the road is decribed by 3 layers :

- 1 coating layer (variable with « COATING_ROAD » or « COAT_ROAD »)
- 1 layer of gravel below (variable with « BASEMENT_ROAD » or « BASE_ROAD »)
- 1 layer of natural soil below (whose characterics are defined from the CLAY and SAND fractions)

Each of these layers is represented by a number of integer levels of the TEB (XTEB_GRIDSOIL) basement grid. In other words, each change between these layers corresponds to a separation of levels of the grid.
The index of the last layer of COATING has the NCOAT_INDEX (the index varies from one point to another, this table is defined in the init phase in the routine init_teb_road_grid_n.F90).
The index of the last layer of basement has the NTEB_ROAD index (it is uniform, correponding to 1m of depth)
In addiction, in order not to have any artifact for the subsoil layer when we use or not GARDEN, CLAY and SAND are now calculated systematically. The default is always 0,33 for each (in particular if one did not fill the namelist NAM_ISBA in the PGD)

For the moment 4 cases for description of soil grid by road grid are defined by CROAD_GRID (init_teb_soil_grid.F90):

- CROAD_GRID = 'LOW3' :
  NTEB_ROAD = 3
  NTEB_SOIL = 3
  XTEB_SOILGRID (NTEB_SOIL) = (/0.01; 0.1;1.0/)

- CROAD_GRID = 'LOW5' :
  NTEB_ROAD = 4
  NTEB_SOIL = 5
  XTEB_SOILGRID (NTEB_SOIL) = (/0.01 ; 0.1 ; 0.5 ;1.0 ; 3.0/)

- CROAD_GRID = 'MEDIUM' :
  NTEB_ROAD = 9
  NTEB_SOIL = 12
  XTEB_SOILGRID (NTEB_SOIL) = (/0.001 ; 0.01 ; 0.05 ; 0.10 ; 0.15 ; 0.20 ; 0.30 ; 0.60 ; 1.00 ; 1.50 ; 2.00 ; 3.00/)

- CROAD_GRID = 'HIGH ' :
  NTEB_ROAD = 11
  NTEB_SOIL = 14
  XTEB_SOILGRID (NTEB_SOIL) = (/0.001 ; 0.005 ; 0.0435 ; 0.0820 ; 0.210 ; 0.338 ; 0.466 ; 0.594 ; 0.768 ; 0.80 ; 1.00 ; 1.50 ; 2.00 ; 3.00/)

New entries in NAM_TEB :

Type	Name	Default	Purpose
CHARACTER (LEN=6)	CROAD_GRID	'LOW5'	Type of vertical grid for soil and roads

New entries in NAM_DATA_TEB :

Type	Name	Default	Purpose
REAL	XUNIF_TC_COATING_ROAD	1.0E+20	Road coating thermal conductivity (W/K/m)
CHARACTER	CFNAM_TC_COATING_ROAD		File name
CHARACTER	CFTYP_TC_COATING_ROAD		File type
REAL	XUNIF_TC_BASEMENT_ROAD	1.0E+20	Road basement thermal conductivity (W/K/m)
CHARACTER	CFNAM_TC_BASEMENT_ROAD		File name
CHARACTER	CFTYP_TC_BASEMENT_ROAD		File type
REAL	XUNIF_HC_COATING_ROAD	1.0E+20	Road coating heat capacity (J/K/m³)
CHARACTER	CFNAM_HC_COATING_ROAD		File name
CHARACTER	CFTYP_HC_COATING_ROAD		File type
REAL	XUNIF_HC_BASEMENT_ROAD	1.0E+20	Road basement heat capacity (J/K/m³)
CHARACTER	CFNAM_HC_BASEMENT_ROAD		File name
CHARACTER	CFTYP_HC_BASEMET_ROAD		File type
REAL	XUNIF_D_COATING_ROAD	1.0E+20	Depth of road coating (m)
CHARACTER	CFNAM_D_COATING_ROAD		File name
CHARACTER	CFTYP_D_COATING_ROAD		File type

Removed from NAM_DATA_TEB :

- XUNIF_TC_ROAD (NROAD_LAYER) : splitted into XUNIF_TC_COATING_ROAD & XUNIF_TC_BASEMENT_ROAD
- XUNIF_HC_ROAD (NROAD_LAYER) : splitted into XUNIF_HC_COATING_ROAD & XUNIF_HC_BASEMENT_ROAD
- XUNIF_D_ROAD (NROAD_LAYER) : replaced by XUNIF_D_COATING

9 Urban soil and hydrology processes

9.1 Methodology

It is possible now to calculate the evolution of the water variables, i.e., the superficial and deep-soil volumetric water content (wg and w2), the equivalent liquid water retained in the vegetation canopy (Wr), the equivalent water of the snow canopy (Ws), and also of the albedo and density of the snow (i.e., SNOWALB and SNOWRHO). Also determine the runoff and drainage into the soil. Computes the evolution of prognostic water reservoirs of urbanized areas.

The roof reservoir runoff goes directly into the road reservoir.

Runoff occurs for road reservoir (too much water), as well as drainage. (Evacuation system, typical time scale: 1 day)

New namelist NAM_DATA_TEB_HYDRO

Type	Name	Default	Purpose
REAL	XUNIF_DENS_WASTE	1.0E+20	Wastewater sewer length density (-)
CHARACTER (LEN=28)	CFNAM_DENS_WASTE		File name
CHARACTER (LEN=6)	CFTYP_DENS_WASTE		File type
REAL	XUNIF_DENS_STORM	1.0E+20	Stormwater sewer length density (-)
CHARACTER (LEN=28)	CFNAM_DENS_STRORM		File name
CHARACTER (LEN=6)	CFTYP_DENS_STORM		File type
REAL	XUNIF_DSEWER	1.0E+20	Waste water sewer depth
CHARACTER (LEN=28)	CFNAM_DSEWER		File name
CHARACTER (LEN=6)	CFTYP_DSEWER		File type
REAL	XUNIF_WS_ROOF_MAX	1.	Max. capacity of surface roof water storage
CHARACTER (LEN=28)	CFNAM_WS_ROOF_MAX		File name
CHARACTER (LEN=6)	CFTYP_WS_ROOF_MAX		File type
REAL	XUNIF_WS_ROAD_MAX	1.	Max. capacity of

			surface road water storage
CHARACTER (LEN=28)	CFNAM_WS_ROAD_MAX		File name
CHARACTER (LEN=6)	CFTYP_WS_ROAD_MAX		File type
REAL	XUNIF_IP_SEWER	0.	Parameter for parasite infiltrations into sewer
CHARACTER (LEN=28)	CFNAM_IP_SEWER		File name
CHARACTER (LEN=6)	CFTYP_IP_SEWER		File type
REAL	XUNIF_CONNEX	1.	Impervious surfaces connexion rate to the sewer
CHARACTER (LEN=28)	CFNAM_IP_SEWER		File name
CHARACTER (LEN=6)	CFTYP_IP_SEWER		File type
REAL	XUNIF_INFIL_ROAD	0.	Water infiltration through the roads
CHARACTER (LEN=28)	CFNAM_INFIL_ROAD		File name
CHARACTER (LEN=6)	CFTYP_INFIL_ROAD		File type
REAL	XUNIF_URBDRAIN	0.	Limitation of urban deep drainage (0-1)
CHARACTER (LEN=28)	CFNAM_URBDRAIN		File name
CHARACTER (LEN=6)	CFTYP_URBDRAIN		File type

New output variables

Name	**Meaning**	**Unit**
DRAIN_GD	Garden deep drainage out of model	$kg/m^2/s$
DRAIN_RD	Road deep drainage out of model	$kg/m^2/s$
DRAIN_BLD	Building deep drainage out of model	$kg/m^2/s$
RUNOFF_WW	Groundwater runoff into wastewater sewers	$kg/m^2/s$
RUNOFF_SW	Groundwater runoff into stormwater sewers	$kg/m^2/s$
DRAINC_GD	Cumulated garden surface drainage	kg/m^2 garden
DRAINC_RD	Cumulated road deep drainage out of model	kg/m^2 road

DRAINC_BLD	Cumulated building deep drainage out of model	kg/m² bld
TOT_WAT_OUT	Cumulative water in town	(mm)
WGS_ROAD	Water storage for road surface and soil column (Out-In)	(mm)
WGS_BLD	Water storage for building surface and soil column (Out-In)	(mm)
WGS_GARDEN	Water storage for garden foliage and soil column (Out-In)	(mm)
HYDRO_BUD	Town water budget of simulation (In-Out)/In*100	kg/m²/s
RUNOFF_WW	Cumulated groundwater runoff into wastewater sewers	kg/m²
RUNOFF_SW	Cumulated groundwater runoff into stormwater sewers	kg/m²
WG_ROAD	Soil liquid water content for soil under roads	m3/m3
WGI_ROAD	Soil ice water content for soil under roads	m3/m3
WG_BLD	soil liquid water content for soil under buildings	m3/m3
WGI_BLD	Soil ice water content for soil under buildings	m3/m3
FSNOW_RD	Fraction of road covered by snow	(1)
FSNOW_RF	Fraction of roof covered by snow	(1)
FWATER_RD	Fraction of road covered by water	(1)
FWATER_RF	Fraction of roof covered by water	(1)
XIRRIG_RD	Road man-made watering rate	kg/m²/s
XIRRIG_GR	Greenroof man-made watering rate	kg/m²/s
XIRRIG_GD	Garden man_made watering rate	kg/m²/s

10 TEB option for high vegetation : street trees or green walls

10.1 Methodology

It is now available to consider tree influence of street trees and green walls in TEB. When GARDEN is activated we can also activated TREE parametrization by activating CURBTREE = 'TREE' (green walls GRWL are not implemented yet).

10.2 Main principle : double energy balance

The idea is to separate the energy balance of high vegetation and low vegetation. The radiative exchanges are calculated either according to Redon et al. (2017), with calculations following canyon street hypothesis and explicit view factors, or with SPARTACUS (Hogan 2019).
The call for high vegetation energy balance calculation is made by a simplified version of ISBA, because only the energy balance of the vegetation (alone) is calculated (and not the soil) (see figure 1).
The water corresponding to evaporation flow is distributed in the soil levels according to the root profile of high vegetation (therefore trees), and the soil water content of the different layers (and corresponding water stress)

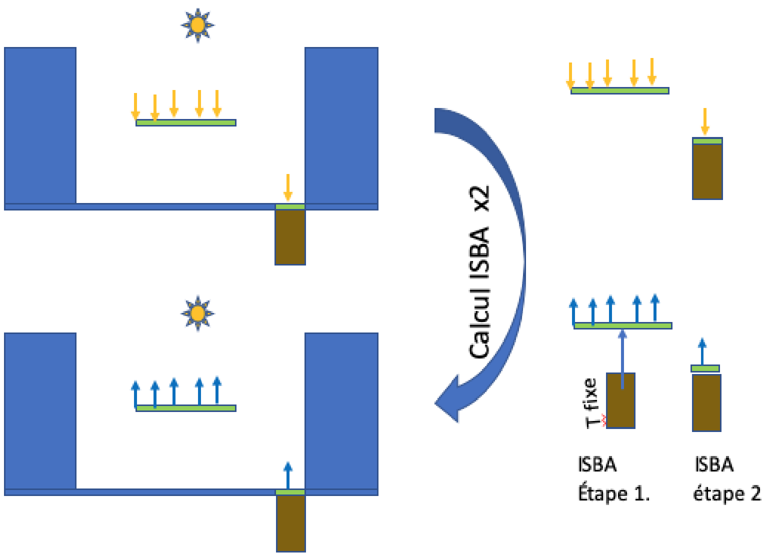

Figure 1: Generic strategy for modelling high vegetation in TEB

The general methodology of the computation of heat and latent fluxes of the high-vegetation canopy is as follows:

- The sensible heat flux corresponds to the heat exchanged between the leaves and the air and depends, in ISBA modeling, on an aerodynamic resistance « Ra ». This is because heat is exchanged at the surface of the leaves.
- The latent flow of evaporation depends both on this aerodynamic resistance, but also on the ability of stomata to open to evaporate water. This is represented by a stomatal resistance « Rs » (figure 3). This is because the exchanged water comes from inside, and not from the

surface, oh the leaves. This « Rs » takes into account the characteristics of plant and its water stress.

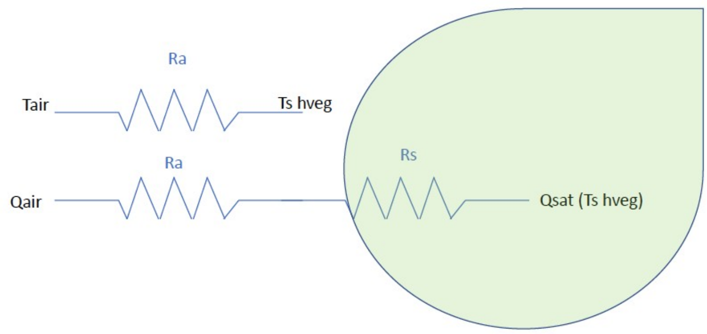

Figure 2: The resistance system at the level of the canopy of high vegetation

The main issue with is the estimate of aerodynamic resistance of the canopy. It it is was too strong in relation to the stomatal resistance, it will give too much weight to the latent exchanges.

TEB is already calculating the micro-meteorological conditions in the canyon at the level of the tree canopy, and therefore of the leaves. The idea was therefore to take into account that the exchanges are local, at he levels of the sheets (and the characteristics of the air that is close to the sheets), and that the roughness corresponds only to the heat exchanges for the calculation of the aerodynamic resistance « Ra ». Note that the influence of all high vegetation on the characteristics of the air is taken into account by the drag force, and the release of energy lows in the canyon.

This calculation amounts to imposing the value of « Ra » so as to have both a correct partition between the latent and sensitive flows, and a correct temperature of the leaves.

So, in the end, for:
- « Rs », one keep the calculation already done in ISBA
- « Ra », one use a characteristics distance to obstacles of 10 cm and a leaves roughness of 3cm. These values were calibrated on SdE Boqer case, so as to have fairly low aerodynamic resistance (exchanges with the air in the immediate vicinity of the cover being easy).

The high vegetation temperature (GH_TV) it is calculated from its own energy balance, inspired by MEB (whithout water and snow interception), and draws water from the soil of Garden. Its heat capacity is calculated as in MEB.

New entries in NAM_TEB

Type	**Name**	**Default**	**Values**	**Purpose**
CHARACTER (LEN=4)	CURBTREE	‘NONE’	‘TREE’, ‘GRWL’	TEB options for the high vegetation : street trees or green walls

New entries in NAM_DATA_TEB_GARDEN

Type	**Name**	**Default**	**Purpose**
CHARACTER (LEN=3)	CSHAPE_GARDEN_HVEG	'CYL' (cylindric shape of crown – urban trees)	Shape of crown for urban trees.
REAL	XUNIF_HTRUNK_HVEG	3.0	Height of TRUNK of trees (m)
CHARACTER (LEN=28)	CFNAM_HTRUNK_HVEG		Name file
CHARACTER (LEN=6)	CFTYP_HTRUNK_HVEG		Type file
REAL	XUNIF_WCROWN_HVEG	5.0	Width of crown of trees (m)
CHARACTER (LEN=28)	CFNAM_WCROWN_HVEG		Name file
CHARACTER (LEN=6)	CFTYP_WCROWN_HVEG		Type file

New output variables LGARDEN = T

Name	**Meaning**	**Unit**
DIR_SW_GD	Direct Sdown received by garden areas	W/m2
SCA_SW_GD	Scattered Sdown received by garden areas	W/m2
SWR_GD	Sdown received by urban green areas	W/m2
LWR_GD	Ldown received by urban green areas	W/m2
XMELT_GD	Snow melt for garden	kg/m2/s
ALB_GD	Albedo for green areas	-
FSNOW_GD	Snow fraction over vegetation	-
XLEG_GD	Latent heat of evaporation over the ground	W/m²
AC_AGG_GD	Aggreg. aeodynamic resistance for green areas	m/s
SWI{ground layer}_GD	soil wetness index for garden ground layer	-
TS_GD	Surface temperature of urban low vegetation	K
TS_GR	Surface temperature of green roofs	K
ROOTFRAC_{nlayer}	Root fraction profile	-
GD_RESPL	Respiration option for garden	-
HV_RESPL	Respiration option for high vegetation	-
GR_RESPL	Respiration option for greenroof	-
New PGD diagnostics output variables		
GD_WSAT	Garden soil porosity by layer	m3/m3

GD_WFC	Garden field capacity by layer	m3/m3
GD_WWILT	Garden wilting point by layer	m3/m3
GD_MPOTSAT	Matric potential at saturation for garden	m
GD_BCOEF	Soil water CH78 b-parameter for garden	-
GD_CONDSAT	Hydraulic conductivity at saturation for garden	m/s

New ouput variables LGARDEN=T and CURBTREE = 'TREE' or 'GRWL'

Name	Meaning	Unit
H_HV	High vegetation sensible heat flux	W/m2
LE_HV	High vegetation latent heat flux	W/m2
RN_HV	High vegetation Net radiation	W/m2
GFLUX_HV	High vegetation storage flux	W/m2
DIR_SW_HV	Sdown received by urban green areas	W/m2
NTR_DIRSW_HV	Direct Sdown received by urban high vegetation corrected from transmission	W/m2
SCA_SW_HV	Scattered Sdown received by urban high vegetation	W/m2
SWA_HV	Sdown absorbed by urban high vegetation	W/m2
LWA_HV	Ldown absorbed by urban high vegetation	W/m2
SWR_HV	Sdown received by urban high vegetation	W/m2
SWR_VEG	Sdown received by urban vegetation	W/m2
LWR_HV	Ldown received by urban high vegetation	W/m2
LWR_VEG	Ldown received by urban vegetation	W/m2
NET_LW_HV	IR rad absorbed by high vegetation	W/m2
TS_HV	Surface temperature of urban high vegetation s foliage	K
SWA_SK	Sdown absorbed by the sky	W/m2
LWA_SK	Ldown absorbed by the sky	W/m2
GH_TV	High vegetation temperature	K

Remark :
A correction is made if the height of the trees is bigger than buildings, in this case we define the height of the trees as equal to the building's one.
If the width of the trunk is bigger than the tree, we define the width os the trunk as half of the tree height. For each point who applying this correction an ouput message will be written.

Remark 2 : Check fractions for TEB
New in TEB :*mode_coherence_frac.F90*

The purpose of this routine is check fraction coherence entered via a namelist. The following test are made :
- Does the namelist contains values for every fractions ?
- Are all fractions positive ?
- Is fractions sum of (building + road + low vegetation + no vegetation) egal 1 for each mesh ?
- Is the fraction of high vegetation lower than the canyon fraction (road + low veg. + no veg.) ?

11 New interpolation of forcing short-wave radiation

11.1 Methodology

Surfex's interpolation of forcing short-wave (SW) in version 8.1 is based on a linear interpolation on the SW for two forcing time steps while the SW does not evolve linearly.
In this version we propose a new interpolation based on the interpolation of theoretical SW radiation given by the solar zenith angle. A linear interpolation in time is made for both the ratio of scattered to total SW radiation and the ratio between actual total and theorical SW radiation.
First, the total downwelling SW for two time steps (SW1, SW2) is calculated :

SW1 = DIR_SW1 + SCA_SW1
SW2 = DIR_SW2 + SCA_SW2

Secondly, the fraction of scattered radiation for two forcing time steps (F_SCA_SW1, F_SCA_SW2) is calculated :

F_SCA_SW1 = SCA_SW1 / SW1
F_SCA_SW2 = SCA_SW2 / SW2

We know the theoretical total downwelling SW radiation for two forcing time steps (SW1_THEO, SW2_THEO) from the solar zenith angle (ZEN1, ZEN2), and the solar constant (I_0) :

SW1_THEO = I_0 cos(ZEN1)
SW2_THEO = I_0 cos(ZEN2)

Then, we can determine the ratio between the total and the theoretical downwelling SW radiation (F_THEO_SW1, F_THEO_SW2) :

F_THEO_SW1 = SW1 / SW1_THEO
F_THEO_SW2 = SW2 / SW2_THEO

We apply a linear temporal interpolation for both the fraction of scattered radiation and the ratio between total and theoretical solar radiation (+ description ZCOEF):

F_SCA_SW_INT = (1- ZCOEF) *F_SCA_SW1 + ZCOEF * F_SCA_SW2
F_THEO_SW_INT = (1- ZCOEF) *F_THEO_SW1 + ZCOEF * F_THEO_SW2

Finally, we calculate the theorical radiation based on intermediate zenith angle :

THEO_SW_INT = I_0 cos(ZEN_INT)
SW_INT = F_THEO_SW_INT * THEO_SW_INT

SCA_SW_INT = F_SCA_SW_INT * SW_INT
DIR_SW_INT = (1 – F_SCA_SW_INT) * SW_INT

11.2 Changes in NAM_IO_OFFLINE default

Type	Name	Default new	Default old	Purpose
LOGICAL	LINTERP_SW	.TRUE.	.FALSE.	Interpolation of the forcing solar radiation with the new method

The method used in the previous versions is removed. In SURFEX-v9.0 the default is the new interpolation method.

12 Key to switch for the urban mixing length computation

12.1 Methodology

There is now a switch for the urban mixing length computation. CURB_LM can be :

- ‘SM10’: Urban mixing lenght is calculated following Santiago and Martili (2010).
- ‘LMEZ’ : Urban mixing lenght is equaal to height above ground.

Default is LMEZ.

The sm10.F90 routine has been rewritten since it contained several bugs. It is now coded as described in Schoetter et al. (2020), which means that there are two differences compared to Santiago and Martilli (2010) :

- The displacement height is limited to 0.75 x PBUILD_HEIGHT
- The mixing length close to the surface is limited to the distance to the surface.

12.2 New entries in NAM_TEB :

Type	Name	Default	Values	Purpose
CHARACTER (LEN=4)	CURB_LM	‘SM10’	‘SM10’, ‘LMEZ’	Option to compute urban mixing length

13 Option to replace urban areas by selected COVER

1.1 Methodology

It is now possible to specifiy LTOWN_TO_COVER= .TRUE. and NREPLACE_COVER=ICOVER such that the urban landuse is replaced by the ECOCLIMAP COVER ICOVER. ICOVER must be present in the domain.

1.2 New entries in NAM_PGD_ARRANGE_COVER :

Type	Name	Default	Values	Purpose
LOGICAL	LTOWN_TO_COVER	.FALSE.		Option to replace urban landuse by the ecoclimap cover ICOVER
REAL	NREPLACE_COVER	‘NONE’		Ecoclimap ICOVER

14 Multi level coupling

14.1 Replace coupling_surf_atm by DUMMY routine

The content of coupling_surf_atmn.F90 is moved to coupling_surf_atm_multi_level_n.F90.
The routine coupling_surf_atm.F90 transfers arguments to coupling_surf_atm_multi_level_n.F90 and sets the number of levels to 1 (KLEV=1). This should make the CALL COUPLING_SURF_ATM work in the atmospheric models using SURFEX in the classical manner and also allows to make a CALL COUPLING_SURF_ATM_MULTI_LEVEL_N.

14.2 New inputs and outputs for multi level coupling

Compared to coupling_surf_atmn.F90, coupling_surf_atm_multi_level_n.F90 has the additional inputs:

- KLEV: The number of atmospheric levels coupled with SURFEX
- PTKE: The prognostic subgrid TKE of the atmospheric model

and outputs:

- PSFTH_SURF: Heat flux at surface level
- PSFTH_WALL: Heat flux at wall level
- PSFTH_ROOF: Heat flux at roof level
- PSFTQ_SURF: Evaporation flux at surface level
- PSFTQ_WALL: Evaporation flux at wall level
- PSFTQ_ROOF: Evaporation flux at roof level
- PCD_ROOF: Drag due to roofs.

15 Add diagnostics for sensible and latent anthropogenic heat flux

In the current version of TEB it was not possible to distinguish the sensible and latent anthropogenic heat releases. Therefore additional diagnostics have been added :

- QINACTSEN [W/m²(urb)]: sensible internal heat release in buildings
- QINACTLAT [W/m²(urb)]: latent internal heat release in buildings

with
QINACT=QINACTSEN+QINACTLAT

The heating and air conditioning demands (HVAC_HT, HVAC_CL) are only sensible heat. In the case air conditioning is employed, the electrical energy (HVAC_CL) consumed by the air conditioning system is used to pump sensible heat and moisture from the inside of the building towards the outside. On some buildings, evaporative cooling towers might be present. They add moisture to the air, which is now diagnosed as anthropogenic heat flux due to evaporative cooling (LE_EVAP_COOL [W/m²(urb)]).

The total sensible and latent anthropogenic heat fluxes are therefore:
QANTSEN=QINACTSEN+HVAC_HT+HVAC_CL+H_TRAACT+H_INDACT
QANTLAT=QINACTLAT+LE_EVAP_COOL+LE_TRAACT+LE_INDACT

16 Inclusion of option for explicit calculation of longwave radiative exchanges

In the older version of TEB, the infrared radiation budget is implicitly calculated separately for each wall. To facilitate the coupling with SPARTACUS, an option to calculate the infrared radiative exchanges explicitly at the start of the time step (LEXPLW) has been coded and a new routine dedicated to the calculation of the infrared exchanges (explicit_longwave) has been added to TEB. If the LSPARTACUS option is enabled, the LEXPLW option must also be enabled.
With the new option LEXPLW (in teb_options), the longwave radiative exchanges between facets are calculated explicitly before the energy budgets of the different facets are solved.

16.1 New entries in NAM_TEB :

Type	Name	Default	Purpose
LOGICAL	LEXPLW	.FALSE.	Option to calculated explicitly the longwave radiative exchanges between facets

17 Inclusion of radiative exhange calculations using SPARTACUS-Surface

17.1 Methodology

The radiative diagrams in the operational meteorological models calculate the radiative exchanges in a very simplified way by considering the density of the upward and downward radiative flux (two-stream approach) and this for each vertical column of the model without taking into account the horizontal exchanges (single approach). -column model). With the increase in the resolution of meteorological models, there is a need to take into account horizontal exchanges, for example between the edges of small clouds (cumulus clouds). It is for this reason that the parameterization of the atmospheric radiative transfer ECMWF atmospheric radiation scheme (ECRAD) developed at the European Center for Medium-Term Meteorological Forecasts (ECMWF) has been extended by the SPeedy Algorithm for Radiative TrAnsfer through cloUd Sides (SPARTACUS) scheme). SPARTACUS-Surface (Hogan, 2019ab) is an adaptation of SPARTACUS to urban or forest canopies. The horizontal radiation exchanges between buildings and trees are represented in the same way as the horizontal exchanges between clouds in the part of SPARTACUS dedicated to the free atmosphere.

Urban climate models including the Town Energy Balance (TEB) use the form factor approach (radiosity approach) to calculate the radiative exchanges in the urban canopy. SPARTACUS-Surface allows a paradigm shift, because this parametrization solves the true radiative transfer equations via the discrete ordinate method instead of greatly simplifying physics. SPARTACUS-Surface assumes that the frequency of the wall-to-wall distances corresponds to a negative exponential function. Hogan (2019a) confirms that this assumption is robust for cities in different regions of the world. This geometric assumption is more flexible than that of a street-canyon of infinite length or regular parallelepipeds which are very common in urban climate models. SPARTACUS-Surface also makes it possible to take into account a variety of building heights, specular reflections (windows), trees higher than buildings and the absorption and diffusion of radiation by the atmosphere in the urban canopy which will allow to consider pollution and urban fog. Integrating SPARTACUS-Surface into TEB is therefore very important to prepare urban meteorological forecasting at the hectometric scale and to be able to better qualify different urban forms in terms of radiative transfer. This chapter describes the coupling between TEB and SPARTACUS-Surface.

17.2 Technical aspects

The source code of SPARTACUS-Surface is a new library external to the code of the EXTERNAL SURFace (SURFEX) which contains TEB. SURFEX is available in open-source (License CECILL-C) and ECMWF has made SPARTACUS-Surface available under an open-source license (Apache License Version 2.0) which makes the distribution and use of TEB-SPARTACUS very easy.

The main routine of SPARTACUS-Surface (radsurf) is called from the main routine of TEB (town_energy_balance). An option (LSPARTACUS) has been added to TEB to allow the user to designate to use SPARTACUS to calculate radiative exchanges with SPARTACUS. In TEB, the calculation of solar radiative exchanges via the classical method is done centrally upstream from the rest of the physical calculations. This is possible because solar radiation does not depend on other prognostic variables of TEB. For infrared radiation, this is not the case, because the emission of infrared radiation depends on the temperature of the walls. Tests have shown that TEB is numerically stable with the LEXPLW option for different meteorological situations and urban morphologies. [For more details see SPARTACUS-Surface User Guide]

17.1 New entries in NAM_TEB :

Type	Name	Default	Purpose
LOGICAL	LSPARTACUS	.FALSE.	Option to calculated explicitly the longwave radiative exchanges between facets

17.2 new namelist : NAM_SPARTACUS

Type	Name	Default	Values	Purpose
LOGICAL	LDO_SW	.TRUE.		Compute shortwave fluxes ?
LOGICAL	LDO_LW	.TRUE.		Compute longwave fluxes ?
LOGICAL	LDO_VEGETATION	.TRUE.		Will vegetation be represented?
LOGICAL	LDO_URBAN	.TRUE.		Will urban areas be represented?
LOGICAL	LUSE_SW_DIRECT_ALBEDO	.FALSE.		Specify ground and roof albedos separately for direct solar radiation?
REAL	XMIN_VEGETATION_FRACTION	1.0E-6		Minimum area fraction below which a vegetation region is removed completely
REAL	XMIN_BUILDING_FRACTION	1.0E-6		Minimum area fraction below which a building region is removed completely
REAL	N_VEGETATION_REGION_URBAN	1	1, 2	Number of regions used to describe urban vegetation (2 needed for heterogeneity)
REAL	NSW	1		Number of spectral bands for solar radiation
REAL	NLW	1		Number of spectral bands for infrared radiation
REAL	N_STREAM_SW_URBAN	4		Number of streams per hemisphere to describe diffuse shortwave radiation, urban areas
REAL	N_STREAM_LW_URBAN	4		Number of streams per hemisphere to describe longwave radiation, urban areas
LOGICAL	LUSE_SYMMETRIC_VEGETATION_SCALE_URBAN	.FALSE.		TRUE : Tree crowns touch each other; Eq. 20 of Hogan et al. (2018). FALSE: Tree crowns separate (shyness); Eq. 19 of Hogan et

				al. (2018).
REAL	XVEGETATION_ISOLATION_FACTOR_URBAN	0.0	[0.0:1.0]	0.0: Dense vegetation region is embedded within sparse region 1.0: Dense vegetation is in physically isolated regions

17.3 Interfacing between TEB and SPARTACUS

The TEB model only knows one average height of buildings and trees per grid point and calculates only one value of the incident, absorbed and reflected radiation per type of wall, in particular for walls that are not discretized in the vertical. The height of trees in TEB must be less than the height of buildings. SPARTACUS works differently, because it solves the radiative transfer by vertical levels which can have any height.
The first coupling between TEB and SPARTACUS retains the one-layer appearance of TEB, while taking advantage of SPARTACUS's ability to simulate multiple vertical levels. The number and height of the vertical levels of SPARTACUS in the urban canopy is chosen taking into account the height of the buildings and trees present in the mesh:

- One or more layers with a maximum height $\Delta z_{SPTS,\ max}$ from the ground to the height of the trees. These layers contain buildings, trees and air. If the height of the trees H_{tree} is less than $\Delta z_{SPTS,\ max}$, then the height of the first layer of TEB-SPARTACUS is equal to H_{tree}.
- One or more layers with a maximum height of $\Delta z_{SPTS,\ max}$ from tree height to building height (H_{build}). These layers contain only buildings and free air.
- A layer of free air above the buildings, required for technical reasons.

The value of $\Delta z_{SPTS,\ max}$ is fixed at 5 m.

With this choice of the vertical grid, all the levels of SPARTACUS contain either the entire coverage of trees and buildings, or no tree or no building and it is not necessary to interpolate the geometric parameters. trees and buildings (surface density, diameter…) in the vertical direction which could cause problems of physical coherence between different geometric parameters.

The SPARTACUS input data is listed below. Some of these parameters are identical to those of TEB, for example the surface density of buildings (λp). This is indicated by 'TEB variable' in the 'origin' column.
SPARTACUS needs a parameter that denotes the characteristic diameter of buildings. Such a parameter does not exist in TEB. It is calculated (Equation 3) by the combination of the equations defining the ground surface density of buildings (λp; Equation 1) and the ground surface density of exterior walls (λw; Equation 2) assuming that the buildings are cylinders of diameter D.

$$\lambda_p = \frac{\Pi D^2/4}{A_{ref}} \quad \text{Équation 1}$$

$$\lambda_w = \frac{\Pi D H_{build}}{A_{ref}} \quad \text{Équation 2}$$

$$D = \frac{4 \ \lambda_p \ H_{build}}{\lambda_w} \quad \text{Équation 3}$$

A_{ref} is the area of the mesh.

TEB includes an LCANOPY option in order to calculate a vertical profile of meteorological parameters in the urban canopy (Surface Boundary Layer) on a different grid than that of SPARTACUS. The temperature values of the vertical levels of the TEB canopy are linearly interpolated on the centers of the vertical levels of SPARTACUS.
TEB includes a wide variety of elements per wall such as snow, solar panels or vegetation on the roofs; roads, snow, bare ground or vegetation on the ground; and windows on the walls. The radiative properties of these different elements must be aggregated for each wall before calling the physical routines of SPARTACUS and the absorbed radiation of the different elements must be calculated after the physical calculations of SPARTACUS.
The following strategy has been developed for the treatment of two elements of a wall with the coverage rates f_1 and f_2, the albedos α_1 and α_2, the emissivities ε1 and ε2, and the surface temperatures T_1 and T_2. The aggregated values of albedo (α_{agg}), emissivity (ε_{agg}), and surface temperature (T_{agg}) of the wall transmitted to SPARTACUS are calculated as follows:

$$\alpha_{agg}=\frac{f_1\alpha_1+f_2\alpha_2}{f_1+f_2}$$ Équation (4)

$$\epsilon_{agg}=\frac{f_1\epsilon_1+f_2\epsilon_2}{f_1+f_2}$$ Équation (5)

$$T_{agg}=\left(\frac{\frac{f_1\epsilon_1\sigma T_1^4+f_2\epsilon_2\sigma T_2^4}{f_1+f_2}}{\sigma\epsilon_{agg}}\right)^{0.25}$$ Équation (6)

SPARTACUS calculates the average solar (SW_i) and infrared (LW_i) radiation incident on the wall. The solar (SW_a) and infrared (LW_a) radiation absorbed by the two elements and required for the physical TEB calculations is calculated according to:

$$SW_{a,1}=(1-\alpha_1)SW_i$$ Équation (7)

$$SW_{a,2}=(1-\alpha_2)SW_i$$ Équation (8)

$$LW_{a,1}=\epsilon_1(LW_i-\sigma T_1^4)$$ Équation (9)

$$LW_{a,2}=\epsilon_2(LW_i-\sigma T_2^4)$$ Équation (10)

The chosen methodology will not work for infrared radiation if multiple spectral bands are used for infrared. But this is not expected in the near future.
SPARTACUS represents the radiative exchanges between trees, walls and free air in more detail than TEB by taking into account the realistic shape of the trees with the characteristic diameter (D_{tree}), a potential variability of the optical thickness of the trees (FSD_{tree}), and a fraction of trees in contact with the walls (FC_{tree}). These parameters are currently hard-coded, but may in the future become TEB input parameters, which will nevertheless require finding reliable databases of these parameters.

SPARTACUS allows you to specify a different air temperature for the plant canopy than for the open air, but TEB does not distinguish these temperatures. As a result, the temperature of the plant canopy is the same as the temperature of the free air.
SPARTACUS also allows us to consider the absorption and scattering of solar and infrared radiation in the urban canopy. This is specified via the extinction coefficients ($k_{ext, air, sw}$, $k_{ext, air, lw}$) and the albedo of a single air diffusion ($\alpha_{ssa, air, sw}$, $\alpha_{ssa, air, lw}$). For the moment these coefficients are hard-coded at 0. In the following, these coefficients could be calculated according to the temperature and humidity of the air as well as the liquid or solid water content (urban fog) or aerosols (urban

pollution).

The albedo of a single leaf scattering for solar radiation ($\alpha_{ssa,\ tree,\ sw}$) is set at 0.4 which corresponds to the integrated value on the solar spectrum according to the literature. This value is set independently of the albedo of urban vegetation in TEB-Classique, which corresponds to the albedo after multiple broadcasts and which is therefore not the physical quantity required by SPARTACUS. The albedo of a single scattering of a leaf for infrared radiation ($\alpha_{ssa,\ tree,\ lw}$) is calculated from the value of the emissivity of trees (ε_{tree}) in TEB according to:

$$\alpha_{ssa,tree,lw} = 1 - \epsilon_{tree} \quad \text{Équation 11}$$

The extinction coefficient of the trees ($k_{ext,\ tree}$) is calculated from the vertical profile of the vertical density of the leaf surfaces (Leaf Area Density; LAD) assuming an isotropy of the leaves:

$$k_{ext,tree} = 0.5\,LAD \quad \text{Équation 12}$$

SPARTACUS allows to take into account a fraction of specular reflections of the walls (fref, specular). It is hard-coded for now and could later be specified depending on the wall material and the glazing fraction.

TEB-SPARTACUS input variables

Name	**Meaning**	**Unit**	**Origin**
BUILDING_FRACTION	Fractional coverage of buildings	-	TEB variable
BUILDING_SCALE	Horizontal scale of buildings	m	Eq. 3
VEG_FRACTION	Fractional coverage of urban trees	-	TEB variable
VEG_SCALE	Horizontal scale of urban vegetation	m	Hardcoded to 5m
VEG_EXT	Vegetation extinction coefficient	1/m	Eq. 12
VEG_FSD	Fractional standard deviation of vegetation optical depth	-	Hardcoded to 0 (no variability in optical thickness)
VEG_CONTACT_FRACTION	Fraction of vegetation edge in contact with walls rather than air	-	Hardcoded to 0
COS_SZA	Cosine of solar zenith angle	-	TEB variable
GROUND_ALBEDO	Ground albedo as composite of snow covered and snow free road, and low vegetation	-	Eq. 4
GROUND_EMISSIVITY	Ground emissivity as composite of snow free and snow covered road, and urban vegetation	-	Eq. 5
GROUND_TEMPERATURE	Skin temperature of the ground, aggregated for low vegetation, snow free and snow covered roads	K	Eq. 6
ROOF_ALBEDO	Roof albedo as composite of snow covered and snow free roofs, green roofs, and solar panels	-	Eq. 4

ROOF_EMISSIVITY	Roof emissivity as composite of snow free and snow covered roof, green roofs, and solar panels	-	Eq. 5
ROOF_TEMPERATURE	Skin temperature of the roofs, aggregated for snow free and snow covered roofs, green roofs, and solar panels	K	Eq. 6
WALL_ALBEDO	Aggregated albedo of the facade	-	Eq. 4
WALL_EMISSIVITY	Wall emissivity as composite of walls and windows	-	Eq. 5
WALL_TEMPERATURE	Skin temperature of the walls aggregated for WALL A, B and the windows	K	Eq. 6
CLEAR_AIR_TEMPERATURE	Air temperature in canopy, separately specifying the temperature of the air in the clear part of a layer	K	Interpolated from TEB canopy levels
VEG_AIR_TEMPERATURE	Air temperature in canopy, separately specifying the temperature of the air in the vegetated part of a layer	K	At the moment "veg" and "veg_air" not different from "air"
VEG_TEMPERATURE	Leaf surface temperature	K	TEB variable
AIR_EXT	Air extinction coefficient (SW & LW)	1/m	Hardcoded to 0
AIR_SSA	Single scattering albedo of air (SW & LW)	-	Hardcoded to 0
VEG_SSA	Single scattering albedo of urban trees (SW)	-	Hardcoded to 0.4
VEG_SSA	Single scattering albedo of urban trees (LW)	-	Eq. 11
WALL_SPECULAR_FRAC	Wall specular fraction	-	Hardcoded to 0

TEB-SPARTACUS output variables

Name	Meaning	Unit	Destination
PDIR_ALB_TWN	Town direct albedo	-	Coupling with the radiative diagram of the atmospheric model
PSCA_ALB_TWN	Town diffuse albedo	-	Coupling with the radiative diagram of the atmospheric model

PREC_SW_GD	Solar radiation received by GD areas	W/m²	Prognostic equations of the energy balance of rooftop vegetation, low vegetation and trees
PREC_SW_RF	Solar radiation received by RF areas	W/m²	
PREF_SW_GRND	Total solar radiation reflected by ground	W/m²	TEB prognostic equations concerning the energy balance of the different facets
PREF_SW_FAC	Total solar radiation reflected by wall	W/m²	
PREF_SW_HV	Total solar radiation reflected by high vegetation	W/m²	
PSCA_SW_GROUND_DOWN	Diffusive downwelling solar radiation at ground level	W/m²	Calculation of the mean radiative temperature
PSCA_SW_GROUND_UP	Diffusive upwelling solar radiation at ground level	W/m²	Calculation of the mean radiative temperature
PSCA_SW_GROUND_HOR	Diffusive solar radiation in horizontal direction at ground level	W/m²	Calculation of the mean radiative temperature
PLW_GROUND_DOWN	Downwelling longwave radiation at ground level	W/m²	Calculation of the mean radiative temperature
PLW_GROUND_HOR	Longwave radiation in horizontal direction at ground level	W/m²	Calculation of the mean radiative temperature
PE_SHADING	Energy that is not reflected by the shading, nor transmitted through the bld, nor absorbed by the window	W/m²	Diagnosis for the quantification of thermal comfort

18 Coherence check's

The purpose is to count all the flows that come into play in the calculation of the energy balance for the town and to validate that the results obtained are physically plausible. That is, during a time step, the sum of all energy fluxes must be exactly equal to the energy store during the time step.

This means, for developers, that:

- if they change the calculus of an existing energy exchange process, this checks that no bug violating energy conservation was done. This is the case of ***modified*** process.
- if they add one process (one additional energy or water flux, or one additional reservoir (of water, or entity with its temperature evolution), they have to modify the routine chek_teb.F90, and the module containing the diagnostics variables for it, in order to describe in the routine these additional processes. This is the case of ***additional*** process.

18.1 Check energy conservation for TEB

New in TEB check_teb.F90 :

When the LCHECK_TEB key is activated, an energy conservation check is made. We look at the sum of the sources and sinks for the sensible and latent heat flux and this must be less than a given value. The model is halted when there is a violation of energy conservation of more than given value XEPS_BDGT_GLOB (default is 1.0E-3 W/m² (urb))
Furthemore, we check for each surface individually (roal, wall, floor, etc) that there is no imbalance in the energy budget. The model is halted when there is a violation of energy conservation of more than given value XEPS_BDGT_FAC (default is 1.0E-6 W/m² (urb)) for each surface.

18.1.1 New entries in NAM_TEB :

Type	Name	Default	Purpose
LOGICAL	LCHECK_TEB	.TRUE.	Key for energy budget verification for TEB
REAL	XEPS_BDGT_GLOB	1.0E-3	Difference allowed in energy budget for TEB for global processes
REAL	XEPS_BDGT_FAC	1.0E-6	Difference allowed in energy budget for TEB for facade processes

18.2 Check for realistic temperatures

In coupling_tebn.F90 it is checked that the temperatures calculated by the model are not unrealistic fot the road, roof and wall. The model is halted when there is a temperature above 373.16 K.

19 OTHERS :

Modification of teb_morpho.F90

- The lowest possible value for WALL_O_HOR (item 5. in teb_morpho.F90) is now calculated using the actual grid size = SQRT(MESH_SIZE) instead of using a hardcoded grid size of 1000 m.

- The highest possible value for WALL_O_HOR (item 6. in teb_morpho.F90) is now calculated using a minimum building size of 5 m instead of 10 m. The value of the lowest possible building size is now no longer hardcoded to facilitate understanding (new local variable ZSIDE_MIN).

Restructuring of coupling_tebn.F90
In coupling_tebn.F90, the switch LATM_CANOPY decides whether the prognostic canopy variables are replaced by the atmospheric models variables and the prognostic canopy equations deactivated.

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