CityGML

Draft Guidelines - Energy ADE version 0.6

CityGML Energy Application Domain Extension

In collaboration with OGC and SIG 3D

February 22, 2016

Revision updates	When	Who
Basis version	03.08.2015	RN
Markdown export	22.10.2015	EM

Authors:

Consortium participating institutes:

- University of Applied Sciences Stuttgart, Germany
- Technische Universität München, Germany
- Karlsruhe Institute für Technologie, Germany
- European Institute for Energy Research, Germany
- RWTH Aachen University / E.ON Energy Research Center, Germany
- HafenCity Universität Hamburg, Germany
- Ecole Polytechnique Fédérale de Lausanne, Switzerland
- Centre Scientifique et Technique du Batiment, France
- Electricité de France, France
- Sinergis, Italy
- M.O.S.S Computer Grafik Systeme, Germany
- Austrian Institute of Technology, Austria

Abstract

The Energy Application Domain Extension (Energy ADE) described in this documentation defines a standardized data model based on the CityGML 2.0 format for urban energy analyses, aiming to be a reference exchange data model between different urban modelling tools and expert databases.

The Energy ADE has been developed since May 2014 by an international consortium of urban energy simulation developers and users, both academic and commercial. To date, the consortium is composed by: University of Applied Sciences Stuttgart, Technische Universität München, Karlsruhe Institute für Technologie, RWTH Aachen University / E.ON Energy Research Center, HafenCity Universität Hamburg, European Institute for Energy Research, Ecole Polytechnique Fédérale de Lausanne, Centre Scientifique et Technique du Batiment, Electricité de France, Sinergis, M.O.S.S Computer Grafik Systeme and Austrian Institute of Technology.

Contents

1 Overview of the Energy Application Domain Extension

The CityGML Energy Application Domain Extension (Energy ADE) aims at extending the CityGML 2.0 standard with energy-related entities and attributes necessary to perform energy analyses at urban scale.

In accordance with the philosophy of CityGML, the Energy ADE aims to be flexible in terms of compatibility with different data qualities, levels of detail and urban energy model complexities (e.g. from monthly energy balance methods as of ISO 13790, to sub-hourly dynamic simulations by means of software programs like CitySim or EnergyPlus). It takes into consideration the INSPIRE Directive of the European Parliament, as well as the recent US Building Energy Data Exchange Specification (BEDES).

Its structure is conceived to be modular and, in its current version, it consists of 5 modules:

- Building Physics module,
- Occupancy module,
- Construction and Material module,
- Energy System module,
- Timeseries and Schedules module.

Some modules can be potentially used and extended also for other applications (e.g. module Occupancy for socio-economics, module Construction and Materials for acoustics or statics, etc).

This document is intended to explain the main characteristics of each module and to provide a number of examples how the Energy ADE entities and attributes relate to the existing CityGML classes. Several XML examples are given as well, in order to facilitate the comprehension of how and where the Energy ADE is embedded into CityGML.

2 Building Physics Module

This module contains the thermal building objects required for building thermal modelling (e.g. calculation of space heating and space cooling demands): ThermalZone, ThermalBoundary, ThermalComponent. These thermal building objects are linked to the CityGML building objects through its _AbstractBuilding, _BoundarySurface, _Opening classes. A Building may have several ThermalZone objects, for instance in the case of mixed-usage building, or to distinguish rooms or zones with difference orientations (i.e. different solar gains). These ThermalZone objects are separated from each other and from the outside by ThermalBoundary objects. These ThermalBoundary objects may or not correspond to the CityGML _BoundarySurface. However, since globalSolarIrradiance incident on _BoundarySurface is an important term of the building energy balance, every ThermalBoundary delimiting the ThermalZone from outside should be related (correspondsTo) with a _BoundarySurface.

2.1 Building, zones and boundaries

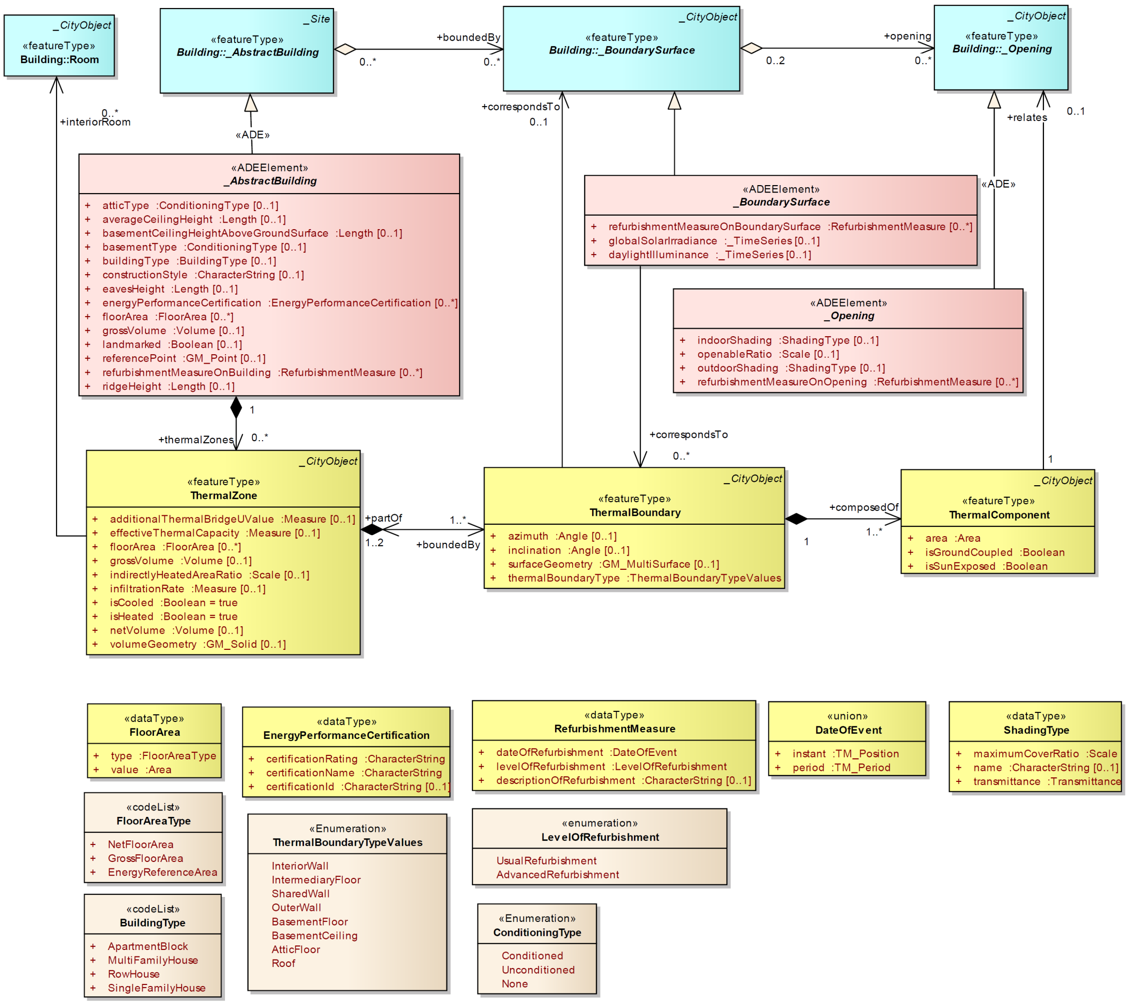
_CityObject
«featureType»
Building::Room
_Site
«featureType»
Building::_AbstractBuilding
+boundedBy
0..*
0..*
_CityObject
«featureType»
Building::_BoundarySurface
+opening
0..2
0..*
_CityObject
«featureType»
Building::_Opening
0..*
+interiorRoom
«ADE»
+correspondsTo
0..1
+relates
0..1
«ADEElement»
_AbstractBuilding
+ atticType :ConditioningType [0..1]
+ averageCeilingHeight :Length [0..1]
+ basementCeilingHeightAboveGroundSurface :Length [0..1]
+ basementType :ConditioningType [0..1]
+ buildingType :BuildingType [0..1]
+ constructionStyle :CharacterString [0..1]
+ eavesHeight :Length [0..1]
+ energyPerformanceCertification :EnergyPerformanceCertification [0..*]
+ floorArea :FloorArea [0..*]
+ grossVolume :Volume [0..1]
+ landmarked :Boolean [0..1]
+ referencePoint :GM_Point [0..1]
+ refurbishmentMeasureOnBuilding :RefurbishmentMeasure [0..*]
+ ridgeHeight :Length [0..1]
«ADEElement»
_BoundarySurface
+ refurbishmentMeasureOnBoundarySurface :RefurbishmentMeasure [0..*]
+ globalSolarIrradiance :_TimeSeries [0..1]
+ daylightIlluminance :_TimeSeries [0..1]
«ADE»
«ADEElement»
_Opening
+ indoorShading :ShadingType [0..1]
+ openableRatio :Scale [0..1]
+ outdoorShading :ShadingType [0..1]
+ refurbishmentMeasureOnOpening :RefurbishmentMeasure [0..*]
1
+thermalZones
0..*
+correspondsTo
0..*
1
_CityObject
«featureType»
ThermalZone
+ additionalThermalBridgeUValue :Measure [0..1]
+ effectiveThermalCapacity :Measure [0..1]
+ floorArea :FloorArea [0..*]
+ grossVolume :Volume [0..1]
+ indirectlyHeatedAreaRatio :Scale [0..1]
+ infiltrationRate :Measure [0..1]
+ isCooled :Boolean = true
+ isHeated :Boolean = true
+ netVolume :Volume [0..1]
+ volumeGeometry :GM_Solid [0..1]
+partOf
1..2
1..*
+boundedBy
_CityObject
«featureType»
ThermalBoundary
+ azimuth :Angle [0..1]
+ inclination :Angle [0..1]
+ surfaceGeometry :GM_MultiSurface [0..1]
+ thermalBoundaryType :ThermalBoundaryTypeValues
+composedOf
1
1..*
_CityObject
«featureType»
ThermalComponent
+ area :Area
+ isGroundCoupled :Boolean
+ isSunExposed :Boolean
«dataType»
FloorArea
+ type :FloorAreaType
+ value :Area
«dataType»
EnergyPerformanceCertification
+ certificationRating :CharacterString
+ certificationName :CharacterString
+ certificationId :CharacterString [0..1]
«dataType»
RefurbishmentMeasure
+ dateOfRefurbishment :DateOfEvent
+ levelOfRefurbishment :LevelOfRefurbishment
+ descriptionOfRefurbishment :CharacterString [0..1]
«union»
DateOfEvent
+ instant :TM_Position
+ period :TM_Period
«dataType»
ShadingType
+ maximumCoverRatio :Scale
+ name :CharacterString [0..1]
+ transmittance :Transmittance
«codeList»
FloorAreaType
+ NetFloorArea
+ GrossFloorArea
+ EnergyReferenceArea
«Enumeration»
ThermalBoundaryTypeValues
InteriorWall
IntermediaryFloor
SharedWall
OuterWall
BasementFloor
BasementCeiling
AtticFloor
Roof
«enumeration»
LevelOfRefurbishment
UsualRefurbishment
AdvancedRefurbishment
«codeList»
BuildingType
+ ApartmentBlock
+ MultiFamilyHouse
+ RowHouse
+ SingleFamilyHouse
«Enumeration»
ConditioningType
Conditioned
Unconditioned
None

Figure 1: Class diagram of Building Physics Module

2.1.1 _AbstractBuilding

The Energy ADE extends the CityGML _AbstractBuilding by a number of energy-related attributes, e.g with regards to the attic and basement type, the construction style, the availability of Energy Performance certificates, etc. It is possible to define different types of floor area (e.g. gross area and net area), as well as to add refurbishment measures applied to the building. In the following, an example of a building is given. Please note that the standard CityGML attributes are omitted for better readability.

```
<!--Examples of Building with Energy ADE attributes-->
<bldg:Building gml:id="id_building_1">
    <gml:description>Description of Building 1</gml:description>
    <gml:name>Name of Building 1</gml:name>

    <energy:referencePoint>
        <gml:Point gml:id="id_building_referencepoint_1" srsName="EPSG:31256" srsDi
            <gml:pos>5 5 0</gml:pos>
        </gml:Point>
    </energy:referencePoint>

    <energy:basementType>Unconditioned</energy:basementType>

    <!--Here follow all EnergyPerformanceCertification objects, each inside a "ene
    <energy:energyPerformanceCertification>
        <energy:EnergyPerformanceCertification >
            <!--Here come all attributes of a EnergyPerformanceCertification objec
        </energy:EnergyPerformanceCertification>
    </energy:energyPerformanceCertification>

    <energy:basementCeilingHeightAboveGroundSurface uom="m">1</energy:basementCeil
    <energy:grossVolume uom="m^3">1050</energy:grossVolume>

    <!--Here follow all RefurbishmentMeasure objects, each inside a "refurbishmen
    <energy:refurbishmentMeasureOnBuilding>
        <energy:RefurbishmentMeasure>
            <!--Here come all attributes of a RefurbishmentMeasure object (omitted
        </energy:RefurbishmentMeasure>
    </energy:refurbishmentMeasureOnBuilding>

    <energy:averageCeilingHeight uom="m">2.7</energy:averageCeilingHeight>
    <energy:atticType>Conditioned</energy:atticType>

    <!--Here follow all UsageZone objects, each inside a "usageZones" tag-->
    <energy:usageZones>
        <energy:UsageZone gml:id="id_usagezone_1">
            <!--Here come all attributes of the first UsageZone (omitted here)-->
        </energy:UsageZone>
    </energy:usageZones>
    <energy:usageZones>
        <energy:UsageZone gml:id="id_usagezone_2">
            <!--Here come all attributes of the second UsageZone (omitted here)--
        </energy:UsageZone>
    </energy:usageZones>

    <energy:ridgeHeight uom="m">10.5</energy:ridgeHeight>
    <energy:landmarked>false</energy:landmarked>

    <energy:floorArea>
        <!--Here come the floorArea attributes (see later)-->
    </energy:floorArea>

    <energy:eavesHeight uom="m">8</energy:eavesHeight>
    <energy:constructionStyle>Massive</energy:constructionStyle>
    <energy:buildingType>MultiFamilyHouse</energy:buildingType>

    <!--Here follow all ThermalZone objects, each inside a "thermalZones" tag-->
    <energy:thermalZones>
        <energy:ThermalZone gml:id="id_thermalzone_1">
            <!--Here come all attributes of the first ThermalZone (omitted here)--
        </energy:ThermalZone>
    </energy:thermalZones>
    <energy:thermalZones>
```

```
        <energy:ThermalZone gml:id="id_thermalzone_2">
            <!--Here come all attributes of the second ThermalZone (omitted here)-
        </energy:ThermalZone>
    </energy:thermalZones>
</bldg:Building>
```

FloorArea

```
<!--Examples of floorArea-->
<energy:FloorArea>
    <energy:type>GrossFloorArea</energy:type>
    <energy:value uom="m^2">50</energy:value>
</energy:FloorArea>

<energy:FloorArea>
    <energy:type>NetFloorArea</energy:type>
    <energy:value uom="m^2">40</energy:value>
</energy:FloorArea>

<energy:FloorArea>
    <energy:type>EnergyReferenceArea</energy:type>
    <energy:value uom="m^2">30</energy:value>
</energy:FloorArea>
```

EnergyPerformanceCertification

```
<!--Example of Energy Performance Certification-->
<energy:energyPerformanceCertification>
    <energy:EnergyPerformanceCertification>
        <energy:certificationRating>GoldStar</energy:certificationRating>
        <energy:certificationName>MyEnergyCertificaton</energy:certificationName>
        <energy:certificationId>0815</energy:certificationId>
    </energy:EnergyPerformanceCertification>
</energy:energyPerformanceCertification>
```

RefurbishmentMeasure

```
<!--Example of a Refurbishment Measure on a building with a very vague date ("bef
<energy:refurbishmentMeasureOnBuilding>
    <energy:RefurbishmentMeasure>
        <energy:dateOfRefurbishment>
            <energy:DateOfEvent>
                <energy:instant indeterminatePosition="before">2010-06</energy:inst
            </energy:DateOfEvent>
        </energy:dateOfRefurbishment>
        <energy:levelOfRefurbishment>UsualRefurbishment</energy:levelOfRefurbishme
    </energy:RefurbishmentMeasure>
</energy:refurbishmentMeasureOnBuilding>

<!--Example of an advanced Refurbishment Measure in the years 1998 and 1999 -->
<energy:refurbishmentMeasureOnBuilding>
    <energy:RefurbishmentMeasure>
        <energy:dateOfRefurbishment>
            <energy:DateOfEvent>
                <energy:period>
                    <gml:TimePeriod>
                        <gml:beginPosition>1998</gml:beginPosition>
                        <gml:endPosition>2000</gml:endPosition>
                    </gml:TimePeriod>
                </energy:period>
            </energy:DateOfEvent>
        </energy:dateOfRefurbishment>
        <energy:levelOfRefurbishment>AdvancedRefurbishment</energy:levelOfRefurbis
    </energy:RefurbishmentMeasure>
</energy:refurbishmentMeasureOnBuilding>

<!--Example of an usual Refurbishment Measure in June 2012 -->
<energy:refurbishmentMeasureOnBuilding>
    <energy:RefurbishmentMeasure>
        <energy:dateOfRefurbishment>
            <energy:DateOfEvent>
                <energy:instant>2012-06</energy:instant>
            </energy:DateOfEvent>
        </energy:dateOfRefurbishment>
        <energy:levelOfRefurbishment>UsualRefurbishment</energy:levelOfRefurbishme
    </energy:RefurbishmentMeasure>
</energy:refurbishmentMeasureOnBuilding>
```

2.1.2 _Opening

The CityGML abstract class _Opening is extended by a number of energy-related attributes, in that openings (namely: windows and doors) may have an indoor and an outdoor shading system. They are further defined by an openable ratio. An example for a window and one for a door are given in the following. As in the Building example shown before, the standard CityGML attributes have been omitted for better readability. The door example is simpler and contains also information about construction and construction orientation (by means of Xlinks).

```
<!--Example of a Window object -->
<bldg:Window gml:id="id_window_1">
    <gml:description>This is Window with an ouside rolling shutter and curtains ins
    <gml:name>Window with rolling shutter and curtains</gml:name>

    <energy:outdoorShading>
        <energy:ShadingType>
            <energy:maximumCoverRatio uom="ratio">1</energy:maximumCoverRatio>
            <energy:name>Rolling shutter</energy:name>
            <energy:transmittance>
                <energy:Transmittance>
                    <energy:fraction uom="ratio">0</energy:fraction>
                    <energy:wavelengthRange>Total</energy:wavelengthRange>
                </energy:Transmittance>
            </energy:transmittance>
        </energy:ShadingType>
    </energy:outdoorShading>

    <energy:indoorShading>
        <energy:ShadingType>
            <energy:maximumCoverRatio uom="ratio">0.5</energy:maximumCoverRatio>
            <energy:name>Curtain</energy:name>
            <energy:transmittance>
                <energy:Transmittance>
                    <energy:fraction uom="ratio">0.8</energy:fraction>
                    <energy:wavelengthRange>Total</energy:wavelengthRange>
                </energy:Transmittance>
            </energy:transmittance>
        </energy:ShadingType>
    </energy:indoorShading>

    <energy:openableRatio uom="ratio">0.9</energy:openableRatio>

</bldg:Window>

<!--Example of a Door object -->
<bldg:Door gml:id="id_door_1">
    <gml:description>This is Door</gml:description>
    <gml:name>Door 1</gml:name>

    <energy:constructionOrientation xlink:href="#id_construction_orientation_door"
    <energy:construction xlink:href="#id_construction_orientation_door"/>

    <energy:openableRatio uom="ratio">0.95</energy:openableRatio>

</bldg:Door>
```

2.1.3 _BoundarySurface

The CityGML abstract class _BoundarySurface is extended by a number of attributes in order to store the incident global solar irradiances and the daylight illuminances available on each outside boundary surface of the building. Moreover, specific information about refurbishmennt measures can also be associated to a certain _BoundarySurface object (e.g. a Roofsurface, a Wallsurface, etc.). The global solar irradiance is the sum of the direct, diffuse and reflected irradiance incident on a outside boundary surface and is generally expressed in Watts per square metre. These global solar irradiance is generally used for the thermal calculations within the buildings (more precisely the

_ThermalZone), but also for the calculation of the energy yield from the solar systems (e.g. photovoltaic and solar thermal panels).

Daylight illuminance is the sum of the direct, diffuse and reflected solar illuminance incident on a outside boundary surface. It is generally expressed in Lux. Daylight illuminance is typically used for outside and inside daylighting study, as well as the calculation of the energy consumptions of lighting systems required to reach the room illuminance threshold when the daylight illuminance is not enough. Both globalSolarIrradiance and daylightIlluminance attributes contain _Timeseries data (see details in Temporal Data Module).

In the following, a XML example of a roof is given.

```
<!--Example of a Roof object -->
<bldg:RoofSurface gml:id="id_roof_1">
    <gml:description>Description of Roof 1</gml:description>
    <gml:name>Name of Roof 1</gml:name>

    <energy:refurbishmentMeasureOnBoundarySurface>
        <energy:RefurbishmentMeasure>
            <!--Here come all attributes of a RefurbishmentMeasure object (omitte
        </energy:RefurbishmentMeasure>
    </energy:refurbishmentMeasureOnBoundarySurface>

    <energy:globalSolarIrradiance>
        <!--Add here the TimeSeries data -->
    </energy:globalSolarIrradiance>

    <energy:daylightIlliminance>
        <!--Add here the TimeSeries data -->
    </energy:daylightIlliminance>

</bldg:RoofSurface>
```

2.1.4 ThermalZone

A ThermalZone is a zone of a building (or of a building part) which serves as the smallest homogeneous, geometrically defined space unit for building heating/cooling simulations. It is considered as isothermal. The ThermalZone may be related to a room (gml:Room), and may optionally contain an explicit volume geometry (e.g. useful for visualisation purposes).

The actual surface boundaries of a ThermalZone are defined by means of ThermalBoudary objects (see later).

The class ThermalZone inherits from _CityObject, and may therefore be associated to one or more EnergyDemand objects (see module Energy Systems). For heating/cooling simulations, the ThermalZone must be related to at least one (or more) UsageZone objects (see Occupancy Module). In the following, the first XML example shows the structure of a ThermalZone without volume geometry. The second one exemplifies instead how to add such an attribute (called volumeGeometry).

```
<!--Example of a ThermalZone-->
<energy:ThermalZone gml:id="id_thermalzone_1">
    <gml:description>Description of Thermal Zone 1</gml:description>
    <gml:name>Name of Thermal Zone 1</gml:name>
    <energy:additionalThermalBridgeUValue uom="W/(K*m^2)">1</energy:additionalTher
    <energy:effectiveThermalCapacity uom="Wh/K">1</energy:effectiveThermalCapacity
    <energy:floorArea>
        <energy:FloorArea>
            <energy:type>NetFloorArea</energy:type>
            <energy:value uom="m^2">40</energy:value>
        </energy:FloorArea>
        <!--Here come further optional values of floorArea-->
    </energy:floorArea>
    <energy:grossVolume uom="m^3">200.0</energy:grossVolume>
    <energy:relates xlink:href="#id_usagezone_1"/>
    <energy:indirectlyHeatedAreaRatio uom="ratio">0</energy:indirectlyHeatedAreaRa
    <energy:infiltrationRate uom="1/h">3</energy:infiltrationRate>
    <energy:isCooled>true</energy:isCooled>
    <energy:isHeated>true</energy:isHeated>
    <energy:netVolume uom="m^3">160.0</energy:netVolume>

    <!--Here follow all ThermalBoundary objects, each inside a "boundedBy" tag-->
    <energy:boundedBy>
```

```
        <energy:ThermalBoundary gml:id="id_thermalboundary_1">
            <!--Here come all attributes of the first ThermalBoundary (omitted her
        </energy:ThermalBoundary>
    </energy:boundedBy>
    <energy:boundedBy>
        <energy:ThermalBoundary gml:id="id_thermalboundary_2">
            <!--Here come all attributes of the second ThermalBoundary (omitted he
        </energy:ThermalBoundary>
    </energy:boundedBy>

    <!--Add more ThermalBoundary objects here (if needed) -->
</energy:ThermalZone>

<!--Example of a ThermalZone with explicit volume geometry-->
<energy:ThermalZone gml:id="id_thermalzone_2">
    <!--Additional attributes of the ThermalZone (omitted here)-->

    <energy:volumeGeometry>
        <gml:Solid gml:id="id_thermalzone_volume_geometry_1" srsName="EPSG:31256" s
            <gml:exterior>
                <gml:CompositeSurface>
                    <gml:surfaceMember>
                        <gml:Polygon>
                            <gml:exterior>
                                <gml:LinearRing>
                                    <gml:posList>0 0 0 0 10 0 5 10 0 5 0 0 0 0 0</g
                                </gml:LinearRing>
                            </gml:exterior>
                        </gml:Polygon>
                    </gml:surfaceMember>
                    <gml:surfaceMember>
                        <gml:Polygon>
                            <gml:exterior>
                                <gml:LinearRing>
                                    <gml:posList>0 0 4 5 0 4 5 10 4 0 10 4 0 0 4</g
                                </gml:LinearRing>
                            </gml:exterior>
                        </gml:Polygon>
                    </gml:surfaceMember>

                    <!--Here come further surfaceMember objects-->

                    </gml:CompositeSurface>
                </gml:exterior>
            </gml:Solid>
        </energy:volumeGeometry>
    </energy:ThermalZone>
```

2.1.5 ThermalBoundary

A ThermalBoundary is a coplanar, or nearly coplanar, surface geometrically delimiting a ThermalZone. A set of ThermalBoundary objects represent therefore the physical boundary of each ThermalZone. In case af adjacent ThermalZones, i.e. when two ThermalZones are divided by a common shared wall, a ThermalBoundary object contains topological information about both adjacent ThermalZones.

Each ThermalBoundary object contains information about its azimut and inclination angles, as well as about which type of ThermalBoundary it is (e.g. an exterior wall, a roof, a cellar ceiling, a floor, etc.). When a ThermalBoundary corresponds to the (external) boundary surfaces of the building, it can be linked to the corresponding _Boundary-Surface object (e.g. a wallsurface, a roofsurface, a groundsurface in LoD2). This could be the case, for example, when performing single ThermalZone simulations using the whole building.

When an intermediate floor or ceiling, or a shared wall between two adjacent ThermalZones in the same building need to be modelled, then it is possible to add an explicit surface geometry by means of the surfaceGeometry attribute.

In the following, two XML examples are given: the first one references a LoD2 _BoundarySurface, the second one models a shared wall explicitly. Please note following rules:

- While separating a thermal zone from the building surrounding, its ThermalBoundaries correspond to the external surfaces of the outer wall/roof/basement floor.

- While separating two thermal zones, its thermal boundaries correspond to the middle of the shared wall (or floor/ceiling).

The following figure represents these different cases in a building side section, relating the Energy ADE objects `ThermalZone` and `ThermalBoundary` to the CityGML objects `Room`.

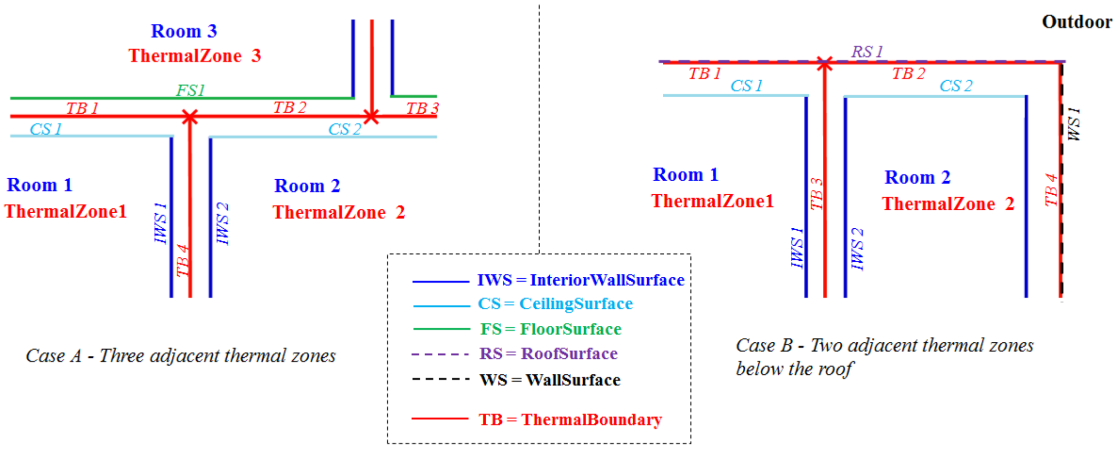

Figure 2: Schema of adjacent thermal zones

```
<!--Example of a ThermalBoundary-->
<energy:ThermalBoundary gml:id="id_thermalboundary_1">
    <gml:description>Thermal Boundary 1</gml:description>
    <gml:name>Thermal Boundary 1</gml:name>
    <energy:azimuth uom="decimal degrees">135</energy:azimuth>
    <energy:inclination uom="decimal degrees">25</energy:inclination>
    <energy:thermalBoundaryType>Roof</energy:thermalBoundaryType>

    <!--Here follow one or more ThermalComponent objects, each inside a "composed
    <energy:composedOf>
        <energy:ThermalComponent gml:id="id_thermalcomponent_1">
            <!--Here come all attributes of the first ThermalComponent (omitted he
        </energy:ThermalComponent>
    </energy:composedOf>
    <energy:composedOf>
        <energy:ThermalComponent gml:id="id_thermalcomponent_2">
            <!--Here come all attributes of the second ThermalComponent (omitted h
        </energy:ThermalComponent>
    </energy:composedOf>
    <partOf xlink:href="#id_thermalzone_1"/>
</energy:ThermalBoundary>
```

An example of how to add explicit multisurface geometry for a ThermalBoundary can be seen in the following example.

```
<!--Example of a ThermalBoundary with explicit surface geometry-->
<energy:ThermalBoundary gml:id="id_thermalboundary_2">
    <!--Additional attributes of the ThermalBoundary class (omitted here)-->

    <energy:surfaceGeometry>
        <gml:MultiSurface gml:id="id_thermalboundary_2_surface_geometry" srsName="E
            <gml:surfaceMember>
                <gml:Polygon>
                    <gml:exterior>
                        <gml:LinearRing>
                            <gml:posList>0 0 0 0 10 0 5 10 0 5 0 0 0 0 0</gml:posLi
                        </gml:LinearRing>
                    </gml:exterior>
                </gml:Polygon>
            </gml:surfaceMember>
        </gml:MultiSurface>
    </energy:surfaceGeometry>
</energy:ThermalBoundary>
```

TO DO: Add a complete example how to model a ThermalBoundary shared between two thermal zones (e.g. a shared wall)

2.1.6 ThermalComponent

A ThermalComponent object is used to semantically model a part of the thermal boundary corresponding to a homogeneous construction component (e.g. windows, wall, insulated part of a wall etc.). For each component, its area is given as well as information whether it is coupled to ground or exposed to sun. As ThermalComponent inherits from _CityObject, it can be associated to a Construction object (see module Construction and Material), either inline or by means of xlinks. A XML example is presented in the following.

```
<!--Example of a ThermalComponent-->
<energy:ThermalComponent gml:id="id_thermalcomponent_1">
    <gml:description>Thermal Component 1</gml:description>
    <gml:name>Thermal Component 1</gml:name>
    <energy:construction xlink:href="#id_construction_1"/>
    <energy:area uom="m^2">50.0</energy:area>
    <energy:isGroundCoupled>false</energy:isGroundCoupled>
    <energy:isSunExposed>true</energy:isSunExposed>
</energy:ThermalComponent>
```

3 Temporal Data Module

3.1 Time Series

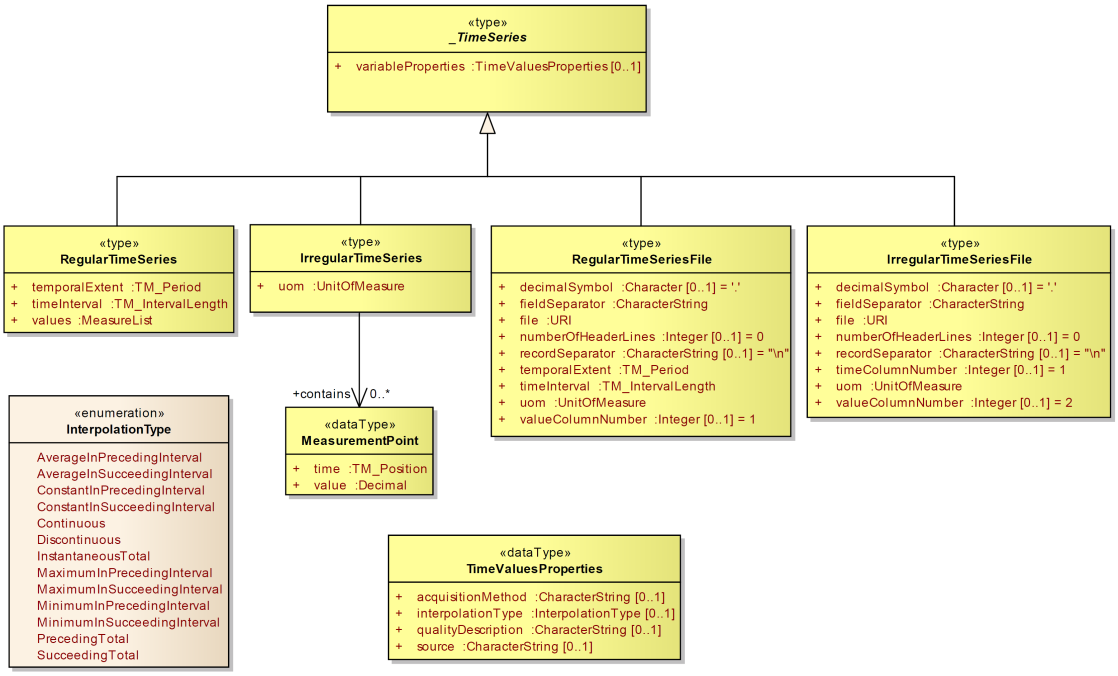
«type»
_TimeSeries
+ variableProperties :TimeValuesProperties [0..1]
«type»
RegularTimeSeries
+ temporalExtent :TM_Period
+ timeInterval :TM_IntervalLength
+ values :MeasureList
«type»
IrregularTimeSeries
+ uom :UnitOfMeasure
«type»
RegularTimeSeriesFile
+ decimalSymbol :Character [0..1] = '.'
+ fieldSeparator :CharacterString
+ file :URI
+ numberOfHeaderLines :Integer [0..1] = 0
+ recordSeparator :CharacterString [0..1] = "\n"
+ temporalExtent :TM_Period
+ timeInterval :TM_IntervalLength
+ uom :UnitOfMeasure
+ valueColumnNumber :Integer [0..1] = 1
«type»
IrregularTimeSeriesFile
+ decimalSymbol :Character [0..1] = '.'
+ fieldSeparator :CharacterString
+ file :URI
+ numberOfHeaderLines :Integer [0..1] = 0
+ recordSeparator :CharacterString [0..1] = "\n"
+ timeColumnNumber :Integer [0..1] = 1
+ uom :UnitOfMeasure
+ valueColumnNumber :Integer [0..1] = 2
+contains
0..*
«enumeration»
InterpolationType
AverageInPrecedingInterval
AverageInSucceedingInterval
ConstantInPrecedingInterval
ConstantInSucceedingInterval
Continuous
Discontinuous
InstantaneousTotal
MaximumInPrecedingInterval
MaximumInSucceedingInterval
MinimumInPrecedingInterval
MinimumInSucceedingInterval
PrecedingTotal
SucceedingTotal
«dataType»
MeasurementPoint
+ time :TM_Position
+ value :Decimal
«dataType»
TimeValuesProperties
+ acquisitionMethod :CharacterString [0..1]
+ interpolationType :InterpolationType [0..1]
+ qualityDescription :CharacterString [0..1]
+ source :CharacterString [0..1]

Figure 3: Class diagram of ADE Energy Core - Time Series

Time series are homogeneous lists of time-depending values. They are used in the Energy ADE to store energy amount or a schedule, for instance. As they actually are a data type which is not domain-specific, they are planned to be integrated in the CityGML 3.0. All time series share some common properties, contained in the variableProperties attribute. These properties are the variable label, the variable unit of measure (*uom*), the interpolation type (based on the WaterML ADE[1]) and some further metadata like the data source, the acquisition method and a quality description.

Time series can be either regular or irregular. *RegularTimeSeries* contain values generated at regularly spaced interval of time (`timeInterval`), over a given `temporalExtent` (i.e. start, end and duration time). They are used, for instance, to store automatically acquired data or hourly/daily/monthly simulation results. In *IrregularTimeSeries*, data follows a temporal sequence, but the measurement points may not happen at a regular time interval[2]. Therefore, each value must be associated with a data or time. What is

[1] http://def.seegrid.csiro.au/sissvoc/ogc-def/resource?uri=http://www.opengis.net/def/waterml/2.0/interpolationType/

[2] IBM knowledge Center[3]

more, each time series can be stored as an external file (e.g. csv or text) and for this purpose a number of attributes provide the required information about how to retrieve the proper set of values from the files. In the following, several examples of time series are given.

```
<!--Example of RegularTimeSeries object with 12 monthly values-->
<energy:RegularTimeSeries gml:id="id_timeseries_electricity_demand_1">
    <energy:variableProperties>
        <energy:TimeValuesProperties>
            <energy:acquisitionMethod>Description of the acquisition method</energ
            <energy:interpolationType>AverageInSucceedingInterval</energy:interpol
            <energy:qualityDescription>Description of data quality</energy:quality
            <energy:source>Information about data source</energy:source>
        </energy:TimeValuesProperties>
    </energy:variableProperties>
    <energy:temporalExtent>
        <gml:TimePeriod>
            <gml:beginPosition calendarEraName="CE">2016-01-01</gml:beginPosition>
            <gml:endPosition calendarEraName="CE">2016-12-31</gml:endPosition>
        </gml:TimePeriod>
    </energy:temporalExtent>
    <energy:timeInterval unit="year">0.0833</energy:timeInterval>
    <energy:values uom="kWh">330 320 300 270 200 180 160 155 170 200 250 300</energ
</energy:RegularTimeSeries>

<!--Example of RegularTimeSeries object with daily values (exerpt)-->
<energy:RegularTimeSeries gml:id="id_timeseries_electricity_demand_2">
    <energy:temporalExtent>
        <gml:TimePeriod>
            <gml:beginPosition calendarEraName="AD">2011-01-01</gml:beginPosition>
            <gml:endPosition calendarEraName="AD">2011-12-31</gml:endPosition>
        </gml:TimePeriod>
    </energy:temporalExtent>
    <energy:timeInterval unit="day">1</energy:timeInterval>
    <energy:values uom="kWh">11.2 11.4 10.2 9.6 6.3 11.5 12.7 ... (truncated, set o
</energy:RegularTimeSeries>
```

```
<!--Example of RegularTimeSeriesFile object with hourly values contained in a fil
<energy:RegularTimeSeriesFile gml:id="id_regulartimeseries_file_1">
    <energy:uom uom="W/m^2"/>
    <energy:file>file_name_containing_values.tsv</energy:file>
    <energy:temporalExtent>
    <energy:temporalExtent>
        <gml:TimePeriod>
            <gml:beginPosition></gml:beginPosition>
            <gml:endPosition></gml:endPosition>
            <gml:duration>P1Y</gml:endPosition>
        </gml:TimePeriod>
    </energy:temporalExtent>
    <energy:timeInterval unit="hour">1</energy:timeInterval>
    <energy:numberOfHeaderLines>1</energy:numberOfHeaderLines>
    <energy:valueColumnNumber>1</energy:valueColumnNumber>
    <energy:fieldSeparator>\t</energy:fieldSeparator>
</energy:RegularTimeSeriesFile>

<!--Example of IrregularTimeSeries object-->
```

3.2 Schedules

The type Schedule is used in the Energy ADE for different kinds of schedules, e.g. heating/cooling schedules (set-point temperatures), ventilation schedules (mechanical air change rate) and occupancy rate. Schedules can be modelled up to 4 “semantic” levels of details depending on the available information and the application requirement. These levels of detail range from a simple constant value to a schedule characterised by a _TimeSeries object.

3.2.1 ConstantValueSchedule

The simplest level of detail, this Schedule is defined by a constant value, generally corresponding to the average parameter value.

```
<!--Example of a ConstantValueSchedule-->
<energy:ConstantValueSchedule gml:id="id_constant_schedule_1">
```

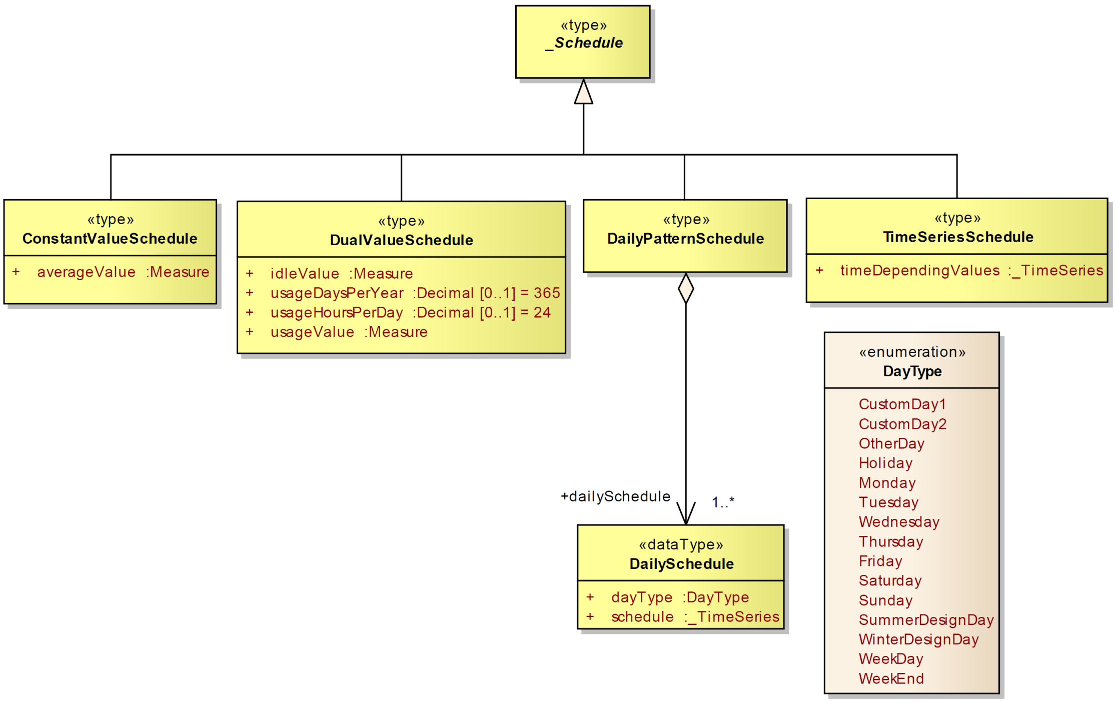

Figure 4: Class diagram of ADE Energy Core - Schedules

```
    <energy:averageValue uom="degree Celsius">26</energy:averageValue>
</energy:ConstantValueSchedule>
```

3.2.2 DualValueSchedule

A two-state schedule, this schedule is defined by a usage value for usage times, and an idle value outside this temporal boundaries. Information about the number of usage days per year and usage hours per usage days are also defined. This schedule complies in particular with the data requirements of the codes and norms describing the monthly energy balance (DIN 18599-2, ISO 13790).

```
<!--Example of a DualValueSchedule-->
<energy:DualValueSchedule gml:id="id_dualvalue_schedule_2">
    <energy:usageValue uom="degree Celsius">20</energy:usageValue>
    <energy:idleValue uom="degree Celsius">16</energy:idleValue>
    <energy:usageHoursPerDay uom="hour">17</energy:usageHoursPerDay>
    <energy:usageDaysPerYear uom="day">365</energy:usageDaysPerYeary>
</energy:DualValueSchedule>
```

3.2.3 DailyPatternSchedule

Detailed schedule composed of daily schedules associated to recurrent day types (weekday, weekend etc.). These daily schedules are Time Series as described above.

```
<!--Example of a daily pattern schedule for a standard day-->
<energy:DailyPatternSchedule gml:id="id_dailypattern_schedule_3">
    <energy:dailySchedule>
        <energy:DailySchedule>
            <energy:dayType>CustomDay1</energy:dayType>
            <energy:schedule>
                <energy:RegularTimeSeries gml:id="id_occupants_daily_timeseries_1">
                    <energy:temporalExtent>
                        <gml:TimePeriod>
                            <gml:beginPosition/>
                            <gml:endPosition/>
                            <gml:duration>P1D</gml:duration>
                        </gml:TimePeriod>
                    </energy:temporalExtent>
                    <energy:timeInterval unit="hour">1</energy:timeInterval>
                    <energy:values uom="ratio">1 1 1 0.74 0.35 ... (truncated, set
                </energy:RegularTimeSeries>
            </energy:schedule>
        </energy:DailySchedule>
    </energy:dailySchedule>
</energy:DailyPatternSchedule>

<!--Example of a daily pattern schedule for a standard week composed of weekday a
<energy:DailyPatternSchedule gml:id="id_dailypattern_schedule_4">
    <energy:dailySchedule>
        <energy:DailySchedule>
            <energy:dayType>WeekDay</energy:dayType>
            <energy:schedule>
                <energy:RegularTimeSeries gml:id="id_occupants_daily_timeseries_2">
                    <energy:temporalExtent>
                        <gml:TimePeriod>
```

```
                            <gml:beginPosition/>
                            <gml:endPosition/>
                            <gml:duration>P1D</gml:duration>
                        </gml:TimePeriod>
                    </energy:temporalExtent>
                    <energy:timeInterval unit="hour">1</energy:timeInterval>
                    <energy:values uom="ratio">0 0 0 0.1 0.2 0.5 ... (truncated, se
                </energy:RegularTimeSeries>
            </energy:schedule>
        </energy:DailySchedule>
    </energy:dailySchedule>
    <energy:dailySchedule>
        <energy:DailySchedule>
            <energy:dayType>WeenEnd</energy:dayType>
            <energy:schedule>
                <energy:RegularTimeSeries gml:id="id_occupants_daily_timeseries_3"
                    <energy:temporalExtent>
                        <gml:TimePeriod>
                            <gml:beginPosition/>
                            <gml:endPosition/>
                            <gml:duration>P1D</gml:duration>
                        </gml:TimePeriod>
                    </energy:temporalExtent>
                    <energy:timeInterval unit="hour">1</energy:timeInterval>
                    <energy:values uom="ratio">0 0 0 0.11 0.22 ... (truncated, set
                </energy:RegularTimeSeries>
            </energy:schedule>
        </energy:DailySchedule>
    </energy:dailySchedule>
</energy:DailyPatternSchedule>
```

3.2.4 TimeSeriesSchedule

Most detailed schedule corresponding to a Time series as described above.

```
<!--Example of a time series based schedule with hourly values for one year-->
<energy:TimeSeriesSchedule gml:id="id_timeseries_schedule_5">
    <energy:RegularTimeSeries "id_occupants_timeseries_5">
            <energy:temporalExtent>
                <gml:TimePeriod>
                    <gml:beginPosition>2000-01-01</gml:beginPosition>
                    <gml:endPosition>2000-12-31</gml:endPosition>
                </gml:TimePeriod>
            </energy:temporalExtent>
            <energy:timeInterval unit="hour">1</energy:timeInterval>
            <energy:values uom="ratio">1 1 1 1 0.9 0.7 0.5 ... (truncated, set of 8
    </energy:RegularTimeSeries>
</energy:TimeSeriesSchedule>
```

4 Construction and Material Module

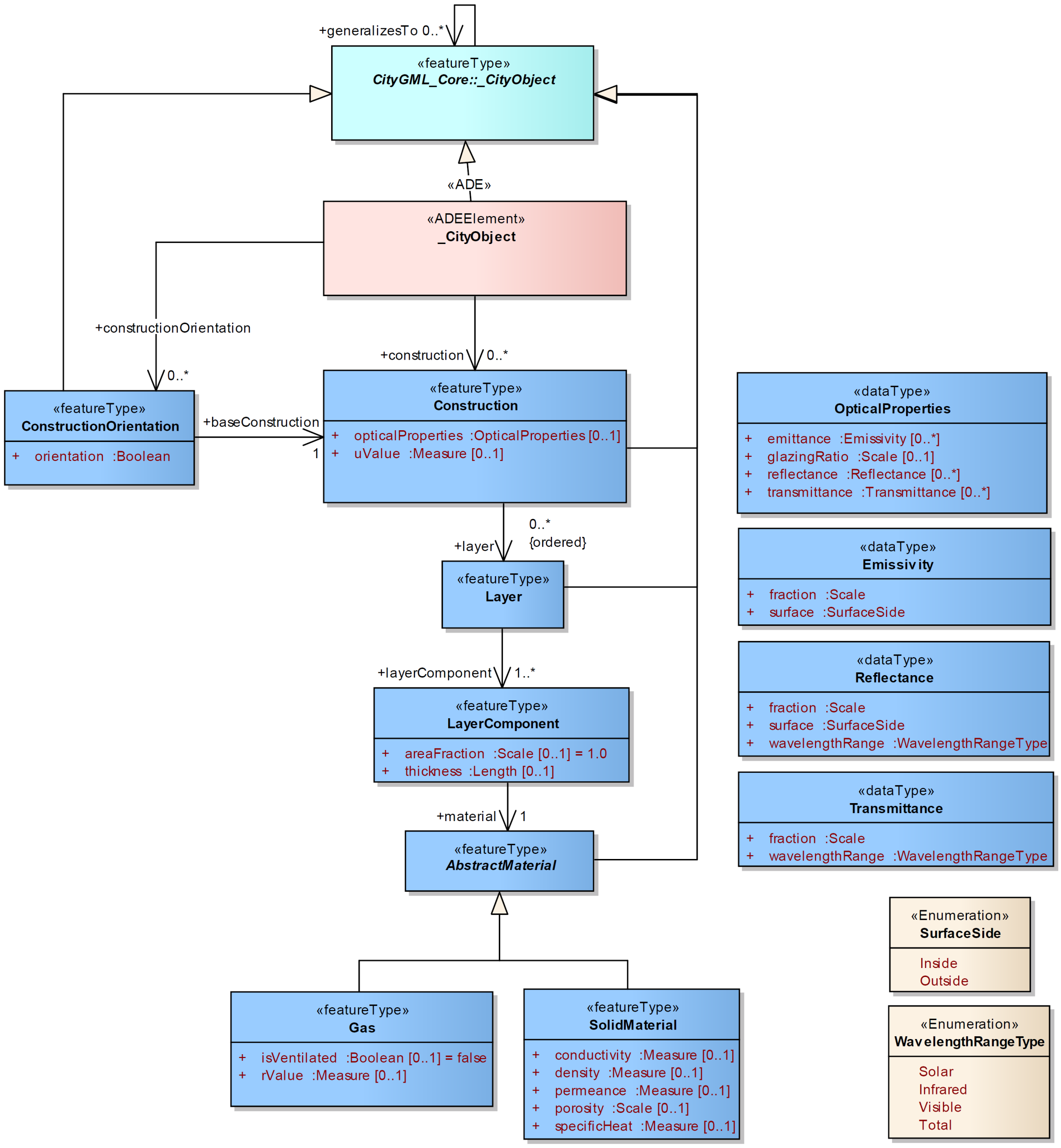

Figure 5: Class diagram of Construction Module

The Construction and Material module of the ADE Energy contains the physical characterization of the boundary surfaces, surface components and, possibly, even the whole building. As it inherits from class `_CityObject`, all similar objects can be described also by means of construction and materials. Given that the nature of this module is not domain-specific, it can be used beyond energy-related applications (e.g. in statics, acoustics etc.)

4.1 Construction

Physical characterisation of building envelop or intern room partition (e.g. wall, roof, openings), it may be specified as an ordered combination of layers. In the Energy ADE, the object Construction can be linked to the `_ThermalComponents`, in order to defined the physical parameters of a walls, roofs of windows, for a space heating/cooling calculation. However, it may possibly be linked to any `_CityObject` for other purposes, in particular to `_BoundarySurface`, `_Opening` or even `_AbstractBuilding`. Each construction object is characterised by a number of attributes like the U-value, or some optical properties, like transmittance, reflecatance and emissivity. In particular, *Transmittance* is the fraction of incident radiation which passes through a specific object. It is specified for a given wavelength range type (`wavelengthRange`). For example, the total transmittance of a window correspond to its *g-value* (also called Solar Heat Gain Coefficient). The transmittance value is included between 0 (completely opaque object) and 1 (completely transparent object). *Reflectance* is the fraction of incident radiation which is reflected by an object. It is specified for a given surface (`SurfaceSide`) and for a given wavelength range type. *Emissivity* is the ratio of the infrared (also called long-wave) radiation emitted by a specific surface/object to that of a black body. It is specified for a given surface (SurfaceSide). According with the Kirchoff and Lambert law, for a diffuse grey body the aborptance and the emittance are equal for a given wavelength range. The sum of the transmittance, reflectance and emissivity (or absorptance) fractions of a surface/object is always 1. In the following, several examples of Construction objects are presented, with different levels of complexity.

```
<!--Example of Construction object-->

<!--Example of a simple wall construction just with a U-value-->
<energy:Construction gml:id="id_construction_2">
    <gml:description>Description of Construction 2</gml:description>
    <gml:name>Name of Construction 2</gml:name>
    <energy:uValue uom="W/(K*m^2)">3.0</energy:uValue>
</energy:Construction>

<!--Example of window Construction object-->
<energy:Construction gml:id="id_construction_2">
    <gml:description>Description of the windows Construction</gml:description>
    <gml:name>Name of the window Construction</gml:name>

    <energy:uValue uom="W/(K*m^2)">1.9</energy:uValue>
    <energy:opticalProperties>
        <energy:OpticalProperties>
            <energy:emittance>
                <energy:Emissivity>
                    <energy:fraction uom="ratio">0.1</energy:fraction>
                    <energy:surface>Outside</energy:surface>
                </energy:Emissivity>
            </energy:emittance>
            <energy:reflectance>
                <energy:Reflectance>
                    <energy:fraction uom="ratio">0.1</energy:fraction>
                    <energy:surface>Outside</energy:surface>
                    <energy:wavelengthRange>Solar</energy:wavelengthRange>
                </energy:Reflectance>
            </energy:reflectance>
            <energy:transmittance>
                <energy:Transmittance>
                    <energy:fraction uom="ratio">0.8</energy:fraction>
                    <energy:wavelengthRange>Solar</energy:wavelengthRange>
                </energy:Transmittance>
            </energy:transmittance>
            <energy:glazingRatio uom="ratio">0.9</energy:glazingRatio>
        </energy:OpticalProperties>
    </energy:opticalProperties>

</energy:Construction>
```

4.2 ConstructionOrientation

This class defines the orientation convention of the `Construction` object it is referred to. In other words, it indicates in which order the layers are to be considered (from inside to outside, or viceversa), because the same construction, if common to different zones or buildings, might be orientated in two different directions for instance.

```
<!--Example of ConstructionOrientation object-->
<energy:ConstructionOrientation gml:id="id_construction_orientation_ground_1">
    <gml:description>Description of Construction Orientation 1 (from inside to outs
    <gml:name>Name of Construction Orientation 1</gml:name>
    <energy:orientation>true</energy:orientation>
    <energy:baseConstruction xlink:href="#id_construction_1"/>
</energy:ConstructionOrientation>
```

4.2.1 Layer

Combination of one of more materials, referenced via a layer component. It inherits from _CityObject.

4.2.2 LayerComponent

Homogeneous part of a layer, covering a given fraction (areaFraction) of the layer.

4.3 Materials

4.3.1 AbstractMaterial

Abstract superclass for all Material classes. A Material is a homogeneous substance. We distinguish solid materials (with mass) from gas (without mass).

4.3.2 SolidMaterial

Class of the materials which have a mass and a heat capacity.

```
<!--Example of a three layered construction-->
<energy:Construction gml:id="ThreeLayeredMaterial">
    <energy:layer>
        <energy:Layer>
            <energy:layerComponent>
                <energy:LayerComponent>
                    <energy:thickness uom="m">0.24</energy:thickness>
                    <energy:material>
                        <energy:SolidMaterial>
                            <gml:name>Concrete 2100</gml:name>
                            <energy:conductivity uom="W/(K*m^2)">2.035</energy:conc
                            <energy:density uom="kg/m^3">2100.0</energy:density>
                            <energy:specificHeat uom="J/(K*kg)">920.0</energy:spec
                        </energy:SolidMaterial>
                    </energy:material>
                </energy:LayerComponent>
            </energy:layerComponent>

            <energy:layerComponent>
                <energy:LayerComponent>
                    <energy:thickness uom="m">0.062</energy:thickness>
                    <energy:material>
                        <energy:SolidMaterial>
                            <gml:name>Insulation 047</gml:name>
                            <energy:conductivity uom="W/(K*m^2)">0.047</energy:conc
                            <energy:density uom="kg/m^3">75.0</energy:density>
                            <energy:specificHeat uom="J/(K*kg)">840.0</energy:spec
                        </energy:SolidMaterial>
                    </energy:material>
                </energy:LayerComponent>
            </energy:layerComponent>

            <energy:layerComponent>
                <energy:LayerComponent>
                    <energy:thickness uom="m">0.025</energy:thickness>
                    <energy:material>
                        <energy:SolidMaterial>
                            <gml:name>Facade</gml:name>
                            <energy:conductivity uom="W/(K*m^2)">0.45</energy:condu
                            <energy:density uom="kg/m^3">1300.0</energy:density>
                            <energy:specificHeat uom="J/(K*kg)">1050.0</energy:spe
                        </energy:SolidMaterial>
                    </energy:material>
                </energy:LayerComponent>
```

```
            </energy:layerComponent>
        </energy:Layer>
    </energy:layer>
</energy:Construction>
```

4.3.3 Gas

Class of the material whose mass and heat capacity are neglectable in comparison with SolidMaterial.

```
<!--Example of a gas material with neglectable mass and heat capacity-->
<energy:Gas>
    <energy:isVentilated>false</energy:isVentilated>
    <energy:rValue uom="m^2*K/W">4.5</energy:rValue>
</energy:Gas>
```

[Picture: Cut of the wall of the same wall - Joachim? Peter?]

5 Occupancy Module

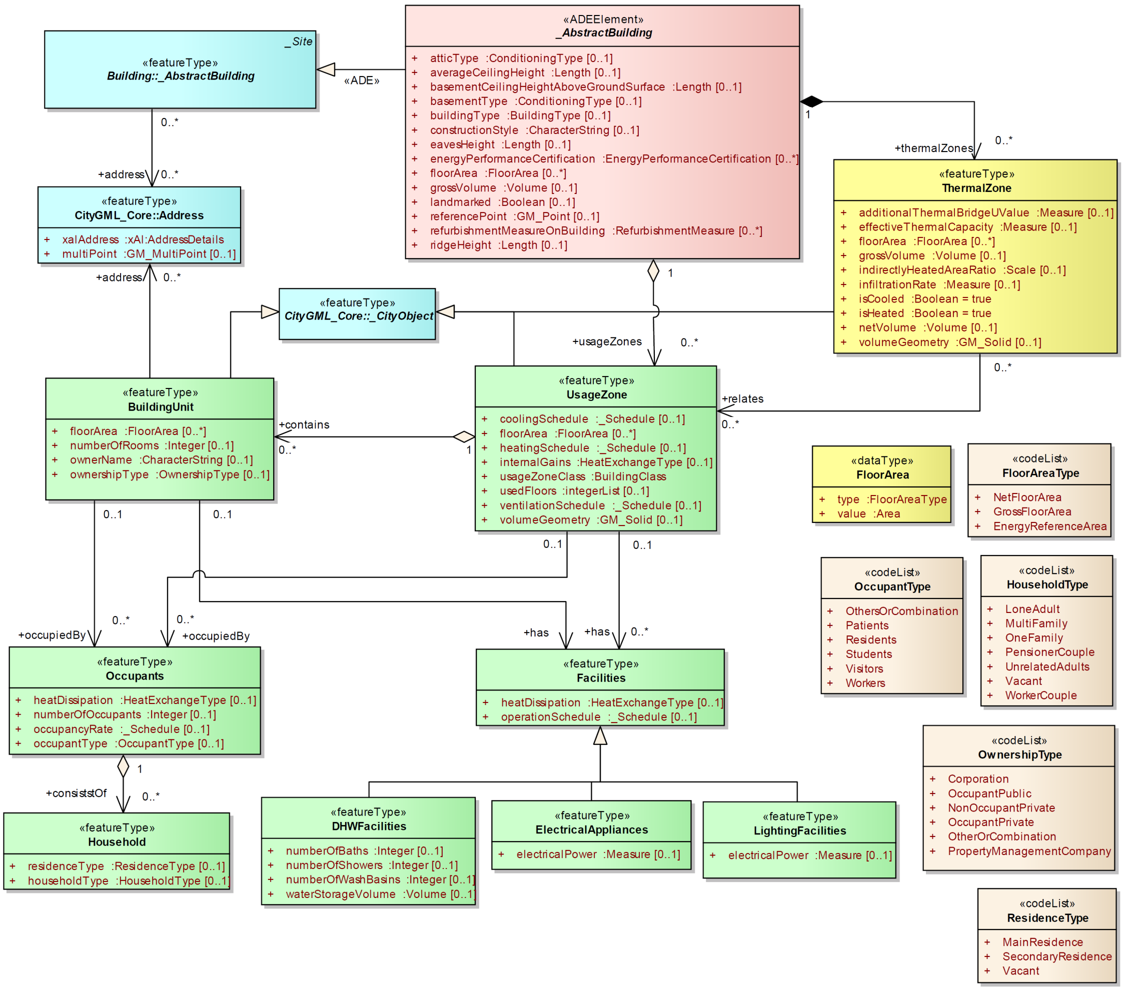
_Site
«featureType»
Building::_AbstractBuilding
«ADE»
«ADEElement»
_AbstractBuilding
+ atticType :ConditioningType [0..1]
+ averageCeilingHeight :Length [0..1]
+ basementCeilingHeightAboveGroundSurface :Length [0..1]
+ basementType :ConditioningType [0..1]
+ buildingType :BuildingType [0..1]
+ constructionStyle :CharacterString [0..1]
+ eavesHeight :Length [0..1]
+ energyPerformanceCertification :EnergyPerformanceCertification [0..*]
+ floorArea :FloorArea [0..*]
+ grossVolume :Volume [0..1]
+ landmarked :Boolean [0..1]
+ referencePoint :GM_Point [0..1]
+ refurbishmentMeasureOnBuilding :RefurbishmentMeasure [0..*]
+ ridgeHeight :Length [0..1]
0..*
+address
0..*
«featureType»
CityGML_Core::Address
+ xalAddress :xAl:AddressDetails
+ multiPoint :GM_MultiPoint [0..1]
+address
0..*
1
+thermalZones
0..*
«featureType»
ThermalZone
+ additionalThermalBridgeUValue :Measure [0..1]
+ effectiveThermalCapacity :Measure [0..1]
+ floorArea :FloorArea [0..*]
+ grossVolume :Volume [0..1]
+ indirectlyHeatedAreaRatio :Scale [0..1]
+ infiltrationRate :Measure [0..1]
+ isCooled :Boolean = true
+ isHeated :Boolean = true
+ netVolume :Volume [0..1]
+ volumeGeometry :GM_Solid [0..1]
1
«featureType»
CityGML_Core::_CityObject
+usageZones
0..*
0..*
«featureType»
BuildingUnit
+ floorArea :FloorArea [0..*]
+ numberOfRooms :Integer [0..1]
+ ownerName :CharacterString [0..1]
+ ownershipType :OwnershipType [0..1]
+contains
0..*
1
«featureType»
UsageZone
+ coolingSchedule :_Schedule [0..1]
+ floorArea :FloorArea [0..*]
+ heatingSchedule :_Schedule [0..1]
+ internalGains :HeatExchangeType [0..1]
+ usageZoneClass :BuildingClass
+ usedFloors :integerList [0..1]
+ ventilationSchedule :_Schedule [0..1]
+ volumeGeometry :GM_Solid [0..1]
+relates
0..*
«dataType»
FloorArea
+ type :FloorAreaType
+ value :Area
«codeList»
FloorAreaType
+ NetFloorArea
+ GrossFloorArea
+ EnergyReferenceArea
0..1
0..1
0..1
0..1
«codeList»
OccupantType
+ OthersOrCombination
+ Patients
+ Residents
+ Students
+ Visitors
+ Workers
«codeList»
HouseholdType
+ LoneAdult
+ MultiFamily
+ OneFamily
+ PensionerCouple
+ UnrelatedAdults
+ Vacant
+ WorkerCouple
+occupiedBy
0..*
0..*
+occupiedBy
+has
+has
0..*
«featureType»
Occupants
+ heatDissipation :HeatExchangeType [0..1]
+ numberOfOccupants :Integer [0..1]
+ occupancyRate :_Schedule [0..1]
+ occupantType :OccupantType [0..1]
«featureType»
Facilities
+ heatDissipation :HeatExchangeType [0..1]
+ operationSchedule :_Schedule [0..1]
1
+consiststOf
0..*
«featureType»
Household
+ residenceType :ResidenceType [0..1]
+ householdType :HouseholdType [0..1]
«featureType»
DHWFacilities
+ numberOfBaths :Integer [0..1]
+ numberOfShowers :Integer [0..1]
+ numberOfWashBasins :Integer [0..1]
+ waterStorageVolume :Volume [0..1]
«featureType»
ElectricalAppliances
+ electricalPower :Measure [0..1]
«featureType»
LightingFacilities
+ electricalPower :Measure [0..1]
«codeList»
OwnershipType
+ Corporation
+ OccupantPublic
+ NonOccupantPrivate
+ OccupantPrivate
+ OtherOrCombination
+ PropertyManagementCompany
«codeList»
ResidenceType
+ MainResidence
+ SecondaryResidence
+ Vacant

Figure 6: Class diagram of Occupancy Module

The Occupancy Module contains the detailed characterization of the building usage, it is related to the rest of the ADE Energy and CityGML model through the class `UsageZone`. Due to the type of information it allows to store, the Occupancy Module may be used also for multi-field analysis (socio-economics, demographics etc.).

5.1 UsageZone

Zone of a building with homogeneous usage type. It is a semantic object, with an optional geometry (`volumeGeometry`), which may be or not related to a geometric entity (Building, BuildingPart, Room etc.).

Its usage type is defined by a `usageZoneClass` (corresponding to the CityGML Code list of the _AbstractBuilding attribute class). This zone is operated with a single heating and cooling set-point temperature schedule (heatingSchedule respectively coolingSchedule) and single air ventilation schedule.

This class inherits from _CityObject and may therefore be associated to 1 or more EnergyDemand objects. This class is defined by at least a usage zone class and a floor area. The building storeys occupied by this UsageZone may be also indicated by means of the attribute usedFloorNumbers, e.g. with 0 corresponding to the ground floor. Its internalGains attribute corresponds to the sum of the energy dissipated from the occupants and the facilities inside the zone.

```
<!--Example of a UsageZone-->
<energy:UsageZone gml:id="id_usagezone_1">
    <gml:description>Description of UsageZone 1</gml:description>
    <gml:name>Name of UsageZone 1</gml:name>
    <energy:usageZoneClass>Commercial</energy:usageZoneClass>
    <energy:usedFloors>1</energy:usedFloors>
    <energy:floorArea>
        <energy:FloorArea>
            <energy:type>NetFloorArea</energy:type>
            <energy:value>40</energy:value>
        </energy:FloorArea>
    </energy:floorArea>
    <energy:internalGains>
        <energy:HeatExchangeType>
            <energy:convectiveFraction uom="ratio">0.6</energy:convectiveFraction>
            <energy:latentFraction uom="ratio">0.1</energy:latentFraction>
            <energy:radiantFraction uom="ratio">0.3</energy:radiantFraction>
            <energy:totalValue uom="kW/m^2">80</energy:totalValue>
        </energy:HeatExchangeType>
    </energy:internalGains>

    <!--Here follow all BuildingUnit objects, each inside a "contains" tag-->
    <energy:contains>
        <energy:BuildingUnit gml:id="id_buildingunit_1">
            <!--Here come all attributes of the first BuildingUnit (if needed) -->
        </energy:BuildingUnit>
    </energy:contains>
    <!--Add more BuildingUnit objects here (if needed) -->

    <!--Here follow all Occupants objects, each inside a "occupiedBy" tag-->
    <energy:occupiedBy>
        <energy:Occupants gml:id="id_occupants_1">
            <!--Here come all attributes of the Occupants object -->
        </energy:Occupants>
    </energy:occupiedBy>

    <!--Here follow all Facility objects, each inside a "has" tag-->
    <energy:has>
        <energy:DHWFacilities gml:id="id_dhwfacilities_1">
            <!--Here come all attributes of a Facility object -->
        </energy:ElectricalAppliances>
    </energy:has>
    <energy:has>
        <energy:ElectricalAppliances gml:id="id_electricalappliance_1">
            <!--Here come all attributes of a Facility object -->
        </energy:ElectricalAppliances>
    </energy:has>
    <energy:has>
        <energy:LightingFacilities gml:id="id_lightingfacility_1">
            <!--Here come all attributes of the Facility object -->
        </energy:LightingFacilities>
    </energy:has>

</energy:UsageZone>
```

TODO: Add examples of cooling, heating and ventilation schedules.

5.2 BuildingUnit

A `BuildingUnit` is a part of a `UsageZone` which is related to a single occupant entity, such as a dwelling or a workplace. Owner information attributes (as owner name and ownership type) are specified in this class. It inherits from class `_CityObject`.

```
<!--Example of a BuildingUnit-->
<energy:BuildingUnit gml:id="id_building_unit_1">
    <gml:description>Description of Building Unit 1</gml:description>
    <gml:name>Name of Building Unit 1</gml:name>

    <energy:numberOfRooms>2</energy:numberOfRooms>
    <energy:ownerName>Lilli's Donuts</energy:ownerName>
    <energy:ownershipType>OccupantPrivate</energy:ownershipType>

    <energy:floorArea>
        <energy:FloorArea>
            <energy:type>NetFloorArea</energy:type>
            <energy:value uom="m^2">40</energy:value>
        </energy:FloorArea>
    </energy:floorArea>

    <!--Here follow all Occupants objects, each inside a "occupiedBy" tag-->
    <energy:occupiedBy>
        <energy:Occupants gml:id="id_occupants_1">
            <!--Here come all attributes of the Occupants object -->
        </energy:Occupants>
    </energy:occupiedBy>

    <!--Here follow all Facility objects, each inside a "has" tag-->
    <energy:has>
        <energy:DHWFacilities gml:id="id_dhwfacilities_1">
            <!--Here come all attributes of a Facility object -->
        </energy:DHWFacilities>
    </energy:has>

</energy:BuildingUnit>
```

5.3 Occupants

An `Occupants` class identifies a homogeneous group of occupants of a usage zone or building unit, defined with an occupant type (e.g. residents, workers, visitors etc.). It can optionally contain one or more Household objects.

```
<!--Example of a Occupants object-->
<energy:Occupants gml:id="id_occupants_1">
    <gml:description>Description of Occupants 1</gml:description>
    <gml:name>Name of Occupants 1</gml:name>

    <energy:heatDissipation>
        <energy:HeatExchangeType>
            <energy:convectiveFraction uom="ratio">0.1</energy:convectiveFraction>
            <energy:latentFraction uom="ratio">0.1</energy:latentFraction>
            <energy:radiantFraction uom="ratio">0.8</energy:radiantFraction>
            <energy:totalValue uom="W/person">80</energy:totalValue>
        </energy:HeatExchangeType>
    </energy:heatDissipation>

    <energy:numberOfOccupants>3</energy:numberOfOccupants>

    <energy:occupancyRate>
        <!--Add here the Schedule data -->
    </energy:occupancyRate>

    <energy:occupantType>Residents</energy:occupantType>

    <!--Here follow all Household objects, each inside a "consistsOf" tag-->
    <energy:consiststOf>
        <energy:Household gml:id="id_household_1">
            <!--Here come all attributes of the first Household (omitted here)-->
        </energy:Household>
    </energy:consiststOf>
    <energy:consiststOf>
        <energy:Household gml:id="id_household_2">
            <!--Here come all attributes of the second Household (omitted here)--
        </energy:Household>
    </energy:consiststOf>
```

```
</energy:Occupants>
```

5.4 Household

A `Household` class identifies a group of persons living in the same dwelling, in the case where occupants are residents. They are defined by a type (e.g. one family, worker couple, etc.) and a residence type (main/secondary residence or vacant).

```
<!--Example of a Household object-->
<energy:Household gml:id="id_household_1">
    <gml:description>Description of Household 1</gml:description>
    <gml:name>Name of Household 1</gml:name>
    <energy:residenceType>SecondaryResidence</energy:residenceType>
    <energy:householdType>UnrelatedAdults</energy:householdType>
</energy:Household>
```

5.5 Facilities

Each `UsageZone` or `BuildingUnit` object can have one or multiple `Facilities` objects. Currently there are three types of facilities (DHWFacilities, ElectricalAppliances and LightingFacilities). Each of them is characterised by the heatDissipation and the operationSchedule attributes, plus some specific ones depending on the facility type. In the following, two XML examples are presented, one for domestic how water facilities and one for electrical applicances. Please note that the lighting facilities object shares the same structure and attributes of the ElectricalAppliances.

```
<!--Example of a DHWFacilities object-->
<energy:DHWFacilities gml:id="id_dhwfacilities_1">
    <gml:description>Description of Domestic Hot Water Facilities 1</gml:descriptio
    <gml:name>Name of Domestic Hot Water Facilities 1</gml:name>

    <energy:heatDissipation>
        <energy:HeatExchangeType>
            <energy:convectiveFraction uom="ratio">0.5</energy:convectiveFraction>
            <energy:latentFraction uom="ratio">0.3</energy:latentFraction>
            <energy:radiantFraction uom="ratio">0.2</energy:radiantFraction>
            <energy:totalValue uom="W/m^2">10</energy:totalValue>
        </energy:HeatExchangeType>
    </energy:heatDissipation>

    <energy:operationSchedule>
        <!--Add here the Schedule data -->
    </energy:operationSchedule>

    <energy:numberOfBaths>1</energy:numberOfBaths>
    <energy:numberOfShowers>0</energy:numberOfShowers>
    <energy:numberOfWashBasins>1</energy:numberOfWashBasins>
    <energy:waterStorageVolume uom="m^3">0.8</energy:waterStorageVolume>
</energy:DHWFacilities>

<!--Example of an ElectricalApplicances object-->
<energy:ElectricalAppliances gml:id="id_electricalappliance_1">
    <gml:description>Description of Electrical Applicance 1</gml:description>
    <gml:name>Name of Electrical Applicance 1</gml:name>

    <energy:heatDissipation>
        <energy:HeatExchangeType>
            <energy:totalValue uom="W/m^2">10</energy:totalValue>
        </energy:HeatExchangeType>
    </energy:heatDissipation>

    <energy:electricalPower uom="kW">1</energy:electricalPower>

    <energy:operationSchedule>
        <!--Add here the Schedule data -->
    </energy:operationSchedule>

</energy:ElectricalAppliances>
```

6 Energy System Module

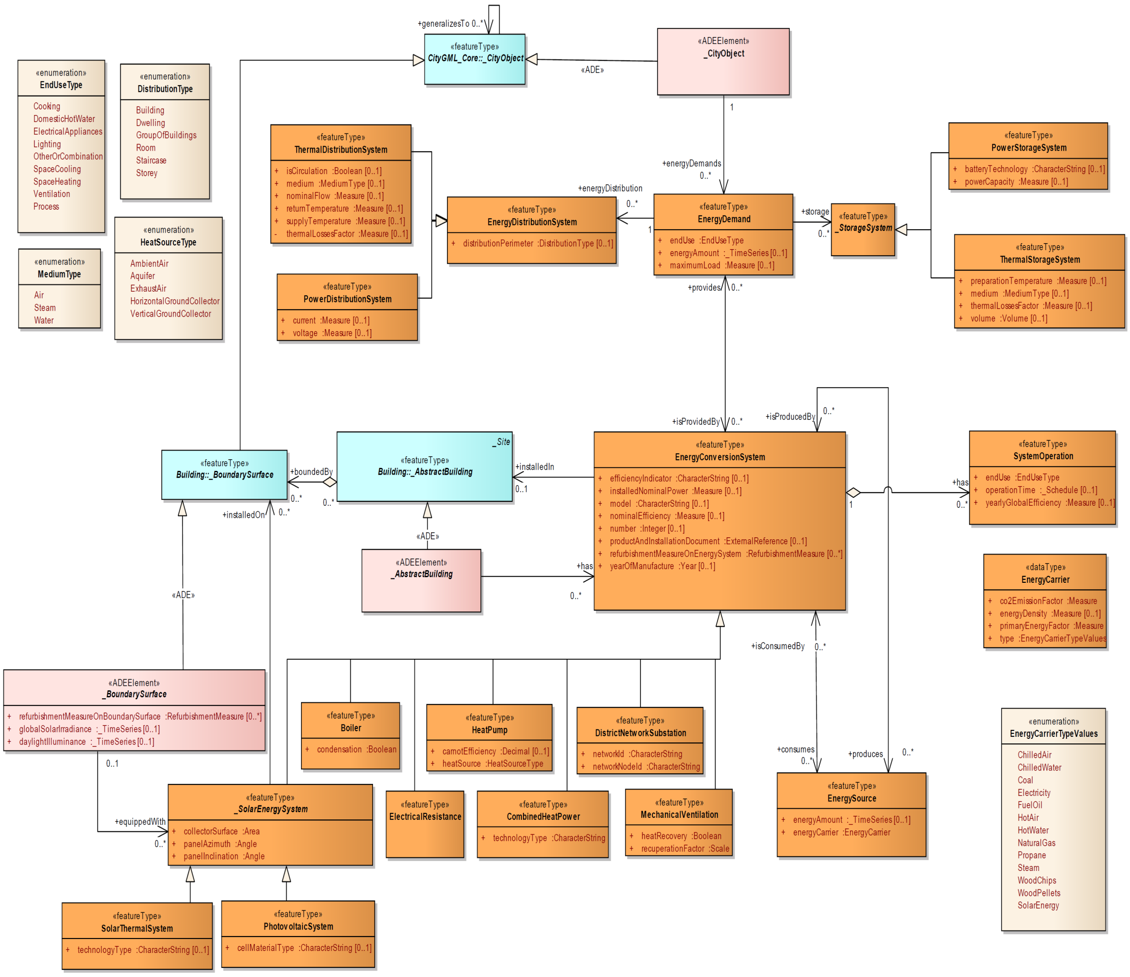
«enumeration»
EndUseType
Cooking
DomesticHotWater
ElectricalAppliances
Lighting
OtherOrCombination
SpaceCooling
SpaceHeating
Ventilation
Process
«enumeration»
DistributionType
Building
Dwelling
GroupOfBuildings
Room
Staircase
Storey
«enumeration»
MediumType
Air
Steam
Water
«enumeration»
HeatSourceType
AmbientAir
Aquifer
ExhaustAir
HorizontalGroundCollector
VerticalGroundCollector
+generalizesTo 0..*
«featureType»
CityGML_Core::_CityObject
«ADE»
«ADEElement»
_CityObject
1
«featureType»
ThermalDistributionSystem
+ isCirculation :Boolean [0..1]
+ medium :MediumType [0..1]
+ nominalFlow :Measure [0..1]
+ returnTemperature :Measure [0..1]
+ supplyTemperature :Measure [0..1]
- thermalLossesFactor :Measure [0..1]
«featureType»
PowerDistributionSystem
+ current :Measure [0..1]
+ voltage :Measure [0..1]
+energyDistribution
0..*
«featureType»
EnergyDistributionSystem
+ distributionPerimeter :DistributionType [0..1]
1
+energyDemands
0..*
«featureType»
EnergyDemand
+ endUse :EndUseType
+ energyAmount :_TimeSeries [0..1]
+ maximumLoad :Measure [0..1]
+storage
0..*
«featureType»
_StorageSystem
«featureType»
PowerStorageSystem
+ batteryTechnology :CharacterString [0..1]
+ powerCapacity :Measure [0..1]
«featureType»
ThermalStorageSystem
+ preparationTemperature :Measure [0..1]
+ medium :MediumType [0..1]
+ thermalLossesFactor :Measure [0..1]
+ volume :Volume [0..1]
+provides
0..*
+isProvidedBy
0..*
+isProducedBy
0..*
«featureType»
Building::_BoundarySurface
+boundedBy
0..*
0..*
+installedOn
0..*
_Site
«featureType»
Building::_AbstractBuilding
+installedIn
0..1
«ADE»
«ADEElement»
_AbstractBuilding
+has
0..*
«featureType»
EnergyConversionSystem
+ efficiencyIndicator :CharacterString [0..1]
+ installedNominalPower :Measure [0..1]
+ model :CharacterString [0..1]
+ nominalEfficiency :Measure [0..1]
+ number :Integer [0..1]
+ productAndInstallationDocument :ExternalReference [0..1]
+ refurbishmentMeasureOnEnergySystem :RefurbishmentMeasure [0..*]
+ yearOfManufacture :Year [0..1]
1
+has
0..*
«featureType»
SystemOperation
+ endUse :EndUseType
+ operationTime :_Schedule [0..1]
+ yearlyGlobalEfficiency :Measure [0..1]
«dataType»
EnergyCarrier
+ co2EmissionFactor :Measure
+ energyDensity :Measure [0..1]
+ primaryEnergyFactor :Measure
+ type :EnergyCarrierTypeValues
«ADE»
«ADEElement»
_BoundarySurface
+ refurbishmentMeasureOnBoundarySurface :RefurbishmentMeasure [0..*]
+ globalSolarIrradiance :_TimeSeries [0..1]
+ daylightIlluminance :_TimeSeries [0..1]
0..1
+equippedWith
0..*
+isConsumedBy
0..*
«featureType»
Boiler
+ condensation :Boolean
«featureType»
HeatPump
+ carnotEfficiency :Decimal [0..1]
+ heatSource :HeatSourceType
«featureType»
DistrictNetworkSubstation
+ networkId :CharacterString
+ networkNodeId :CharacterString
«featureType»
_SolarEnergySystem
+ collectorSurface :Area
+ panelAzimuth :Angle
+ panelInclination :Angle
«featureType»
ElectricalResistance
«featureType»
CombinedHeatPower
+ technologyType :CharacterString
«featureType»
MechanicalVentilation
+ heatRecovery :Boolean
+ recuperationFactor :Scale
+consumes
0..*
+produces
0..*
«featureType»
EnergySource
+ energyAmount :_TimeSeries [0..1]
+ energyCarrier :EnergyCarrier
«enumeration»
EnergyCarrierTypeValues
ChilledAir
ChilledWater
Coal
Electricity
FuelOil
HotAir
HotWater
NaturalGas
Propane
Steam
WoodChips
WoodPellets
SolarEnergy
«featureType»
SolarThermalSystem
+ technologyType :CharacterString [0..1]
«featureType»
PhotovoltaicSystem
+ cellMaterialType :CharacterString [0..1]

Figure 7: Class diagram of Energy System Module

The Energy System Module is a module of the ADE Energy which contains information concerning the energy forms (energy demand, supply, sources) and the energy systems (conversion, distribution and storage systems). It is arranged around one central `EnergyDemand` object.

6.1 EnergyDemand

Useful energy required to satisfy a specific end use, such as heating, cooling, domestic hot water etc. Beside its `EndUseType`, this object is characterized its `energyAmount` (time-depending energy demand value) and its maximum yearly load (`maximumLoad`) used for the sizing of the energy systems.

Every `_CityObject` (typically `ADE:_AbstractBuilding`, `ThermalZone`, `UsageZone` and `BuildingUnit`) may have one or more `EnergyDemand`.

6.1.1 EndUseType

List of possible end uses as cooking, space heating and ventilation.

6.1.2 EnergySource

Final energy consumed (and sometimes produced) by the energy conversion system. Its energy characteristics are specified in the Energy Carrier object.

6.1.3 EnergyCarrier

Primary energy and CO_2 emission factors, energy density and energy carrier type characterize this data type for energy carriers.

6.1.4 EnergyCarrierType

List of energy carriers as coal, chilled water or electricity.

6.2 Energy Distribution

6.2.1 EnergyDistributionSystem

System in charge of delivering the energy inside the building, from the place of energy production to the place of end-use. Power and Thermal distribution systems are differentiated. They all share a distribution perimeter that is described by the distribution type.

6.2.2 Distribution Type

A list of possible distribution perimeters, e.g. Building, Dwelling, Room.

6.2.3 ThermalDistributionSystem

Type for thermal distribution systems with attributes for circulation (circulating system or not), the used medium, nominal flow, return and supply temperatures and thermal losses factor.

6.2.4 PowerDistributionSystem

Type for electrical distribution systems, described by current and voltage.

6.2.5 MediumType

This list is a collection of medium types as air and water.

6.3 Energy Storage

6.3.1 StorageSystem

System storing energy. A same storage may store the energy of different end-users and different end uses. Power and Thermal storage systems are differentiated.

6.3.2 ThermalStorageSystem

Thermal storages with a medium, preparation temperature, thermal losses factor and a volume.

6.3.3 PowerStorageSystem

Electrical storages with an electrical capacity and a string to describe the battery technology.

6.4 Energy Conversion

6.4.1 EnergyConversionSystem

System converting an energy source into the energy necessary to satisfy the `EnergyDemand` (or to feed the networks).

Energy conversion systems have common parameters: efficiency indicator, nominal installed power, nominal efficiency (in reference to an efficiency indicator), year of manufacture, name of the model, a serial number, a reference to product or installation documents and optionally refurbishment measures. They may be one or more (in this case, the nominal installed power corresponds to the totality).

Specific energy conversion systems may have in addition specific parameters:

A same system may have several operation modes (e.g. heat pump covering heating and domestic hot water demands).

6.4.2 SystemOperation

It details the operation of the energy conversion system for a specific end-use and operation time. For instance, a reversible heat pump may have 3 operation modes: heating production in winter, cooling production in summer, and hot water production during the whole year. Attributes are end use type, a schedule for operation time and yearly global efficiency.

6.4.3 DistrictNetworkSubstation

Subtype of `EnergyConversionSystem` for heating or cooling networks substations. Adds attributes for network ID and network node ID.

6.4.4 HeatPump

Subtype of `EnergyConversionSystem` for heat pumps to add carnot efficiency and heat source. Heat source is described using a `HeatSourceType`.

6.4.5 HeatSourceType

List of heat source types for heat pumps, e.g. ambient air, aquifer and exhaust air.

6.4.6 ElectricalResistance

Subtype of `EnergyConversionSystem` for electrical resistances. Comes without additional attributes.

6.4.7 MechanicalVentilation

Subtype of `EnergyConversionSystem` for ventilation systems with attributes heat recovery (with or without) and recuperation factor.

6.4.8 CombinedHeatPower

Subtype of `EnergyConversionSystem` for CHP systems. Utilizes a string describing the technology type.

6.4.9 Boiler

Subtype of `EnergyConversionSystem` for boiler. Defines if it is a condensation boiler or not.

6.4.10 SolarEnergySystem

Subclass of `EnergyConversionSystem` for solar energy systems. Has attributes for collector surface, azimuth and inclination. Differentiates into solar thermal and photovoltaic systems.

6.4.11 SolarThermalSystem

Subtype of `SolarEnergySystem` for thermal systems. Uses a string to describe the technology type.

6.4.12 PhotovoltaicSystem

Subtype of `SolarEnergySystem` for photovoltaic systems. Defines the material type of photovoltaic cells with a string.

References