ESRU
Technical Report

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ESP-r Data Model Decomposition

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This document presents a formal data decomposition of the ESP-r system in terms of its building-side, network flow and control data model. It also includes a decomposition of the principal performance (output) parameters. It uses the symbolism of ATLIAM to express the relationships within the data model and each diagram is accompanied by descriptive text.

1.0 Introduction

This document presents a formal data decomposition of the ESP-r system in terms of its building-side, network flow and control data model. It also includes a decomposition of the principal performance (output) parameters. Plant systems, electrical power, computational fluid dynamics, multi-gridding and some of the more esoteric control options have yet to be decomposed.

The presentation takes the form of ATLIAM diagrams (originally created as part of the COMBINE project [Augenbroe 1992]) with accompanying commentary. The diagrams have been updated to take into account revisions to the data model for ESP-r as of the summer of 1998.

Although much of the decomposition of the ESP-r data model is straightforward, ESP-r holds some types of information in two forms (e.g. thermophysical properties associated with each surface and a named attribute which points to an entry in a database) and it is not clear which representation is preferable. Where this is the case, both representations have been included.

The following text gives information on all the entities in the decomposition. The ATLIAM diagrams have been grouped into sections as follows: Section 2 covers high level descriptions, 3 describes building and zone entities, 4 describes geometry, 5 deals with constructions (thermophysical properties, 6 operations (occupancy, small power, air flow), 7 defines schedules used throughout ESP-r, 8 covers building-side control, 9 defines output schema, 10 defines flow networks and 11 their control.

The diagrams should be understood in the context of the symbols shown in Figure 1. Entities which are on more than one diagram have the CLONE symbol of a square box. The box between entities is equivalent to Condensation_risk HAS Condensation_detail. The arrow between entities indicates that Condensation_risk is a subtype of Performance_assessment_requirement. Further information can be found in [Augenbroe 1992, Clarke et al. 1995].

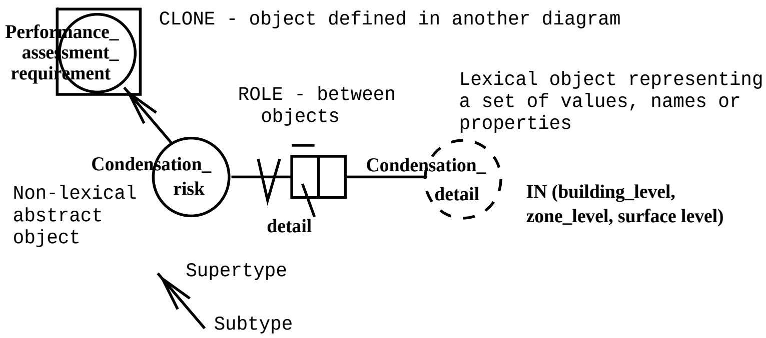

Figure 1 ATLIAM symbolism.

2 High Level Entity Descriptions

2.1 ESP_r

ESP_r (Figure 2) is the top level diagram for the simulation environment. It links the inputs (the Performance_assessment_requirement and the Problem_composition) and uses Modelling_parameter to output (Building_property, Problem_composition, and Performance_assessment).

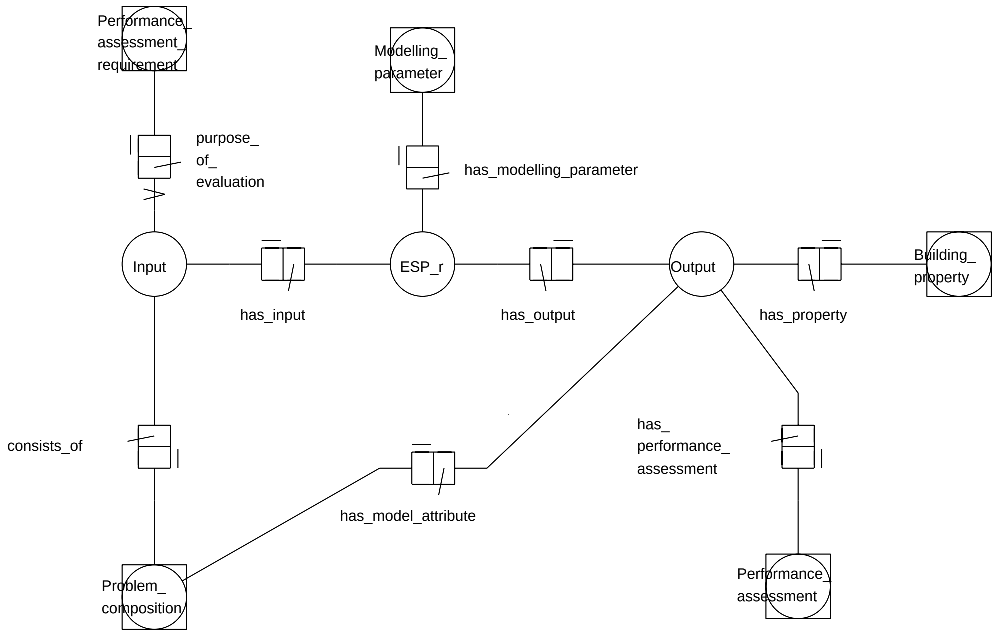

Figure 2 ESP_r diagram.

Performance_assessment_requirement contains the information necessary for the user to initiate a particular design tool function, i.e. the particular analysis required.

Problem_composition is the definition of the problem, which will be the fully or partially attributed model. After attribution (operational, constructional and control information) it becomes an output.

Modelling_parameter contains simulation-related parameters, e.g. start and stop times of the simulation, start-up simulation period, time-step period and control, alternative algorithms for some of the heat transfer processes, etc.

Performance_assessment contains the primary outputs of ESP-r as a thermal performance evaluation tool.

Building_property contains some of the internally calculated properties of the building which may be of use in other design tools.

2.2 ESP_r_problem

The **ESP_r_problem** (Figure 3) is the top entity for the definition of the problem. It shows how Building, Plant and Flow can be separately or jointly simulated, and gives the context of the problem.

Context defines the boundary conditions in the simulation and comprises Site_detail (building location and its situation), External_climate (meteorological data), Pressure_coefficients (boundary conditions for wind-induced airflow analysis), and Ground_temperature (sets of monthly ground temperatures) .

Building is the highest level entity for building-side simulations, and can optionally have flow, plant, power and moisture networks connected to it. It has associated Building_control which represents the control systems on the building side.

Plant is the highest level entity for plant simulations. A Flow_network and a Building can be associated with a plant system. It has associated Plant_control. Neither Plant or Plant_control have been decomposed.

Flow_network is the highest level entity for flow simulations. Both air and liquid flow networks are possible, connected as appropriate (and optionally) to the building and plant systems. There may be more than one network. There is an associated Flow_control which represents the control systems for fluid flow.

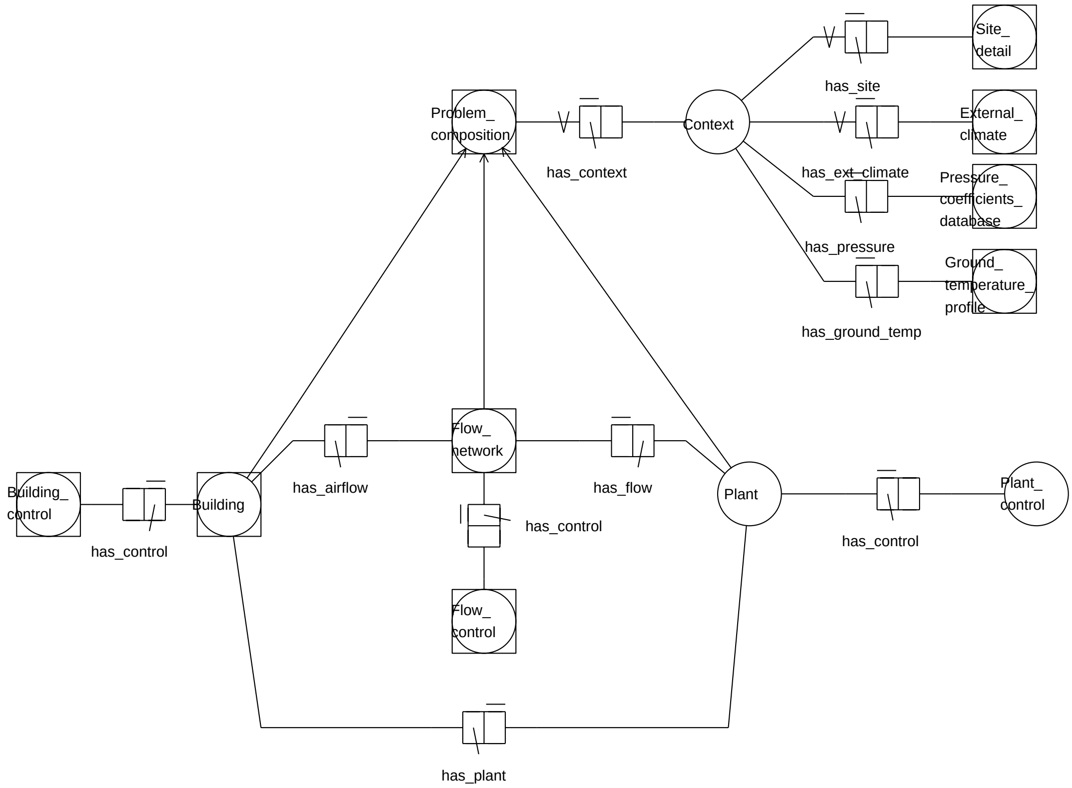

Figure 3 ESP_r_problem diagram (referenced by: ESP-r, building, flow, plant).

2.3 Performance_assessment_requirement

Performance_assessment_requirement (Figure 4) comprise the information necessary for the ESP-r user to initiate a particular design tool function (i.e. the particular analysis required and the information to be returned). There are six subtypes considered: Energy_balance (relative magnitudes of energy fluxes), Plant_size (capacity assessment), Condensation_risk, Energy_consumption (demand over time), Heating_risk (risk of overheating or underheating) and Comfort.

Associated data are: Zone_name (list of names or "all" for the collection of zones) to be assessed, Dates_of_assessment (period over which the assessment is to be made as a Standard_period or a User_specified_date), Temperature_criterion (range or frequency bin of temperatures), Condensation_detail (search criteria for whole building or a portion of the building) and Comfort search criteria and one or more comfort_measures (PMV, PPD or "comfortable, pleasant", "slightly cool, acceptable", etc).

2.4 External_climate

External_climate (Figure 5) is the top level entity for meteorological data. It has a start and stop date, usually, but not necessarily January 1st and December 31st. The entities Climate_station_name (site location), Latitude (positive for northern hemisphere) and Longitude_difference (difference from the standard meridian where positive is eastwards) relate to the location of the climate collection station.

Associated data are: Hourly_climate_value(s) which comprise diffuse radiation (on the horizontal plane), external temperature (dry-bulb temperature), wind speed and direction (clockwise from north), relative humidity, plus either direct normal or global horizontal radiation.

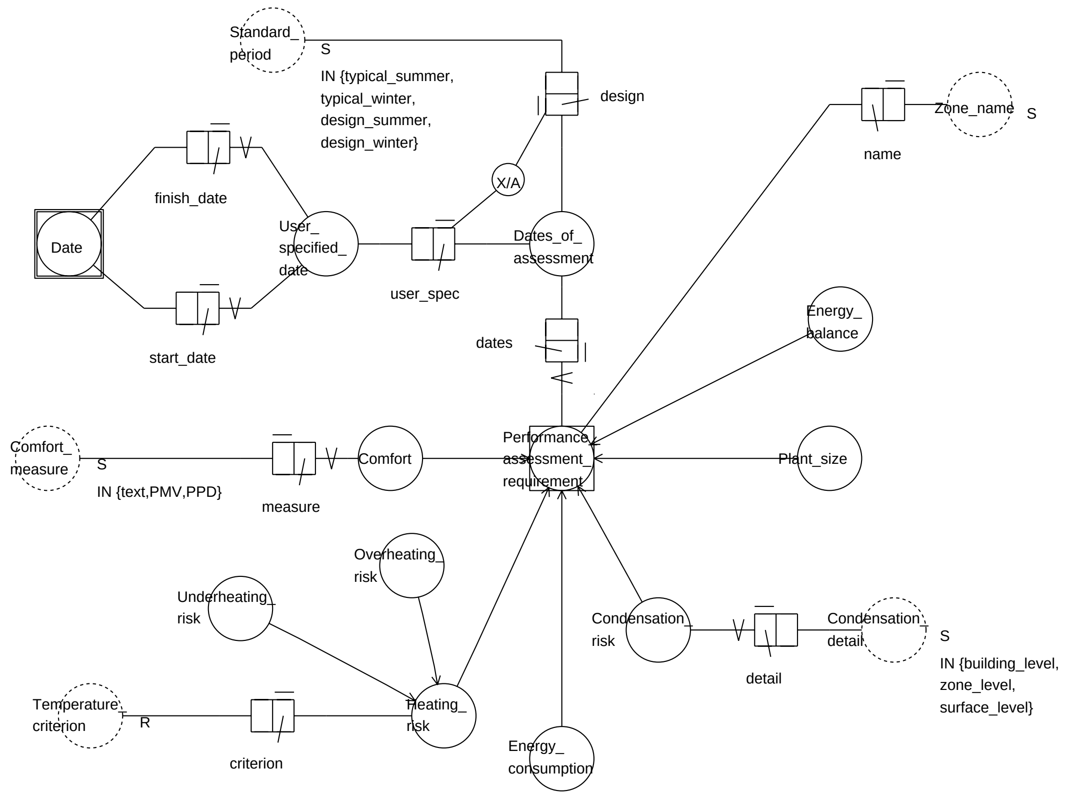

Figure 4 Performance_requirement diagram (referenced by ESP-r).

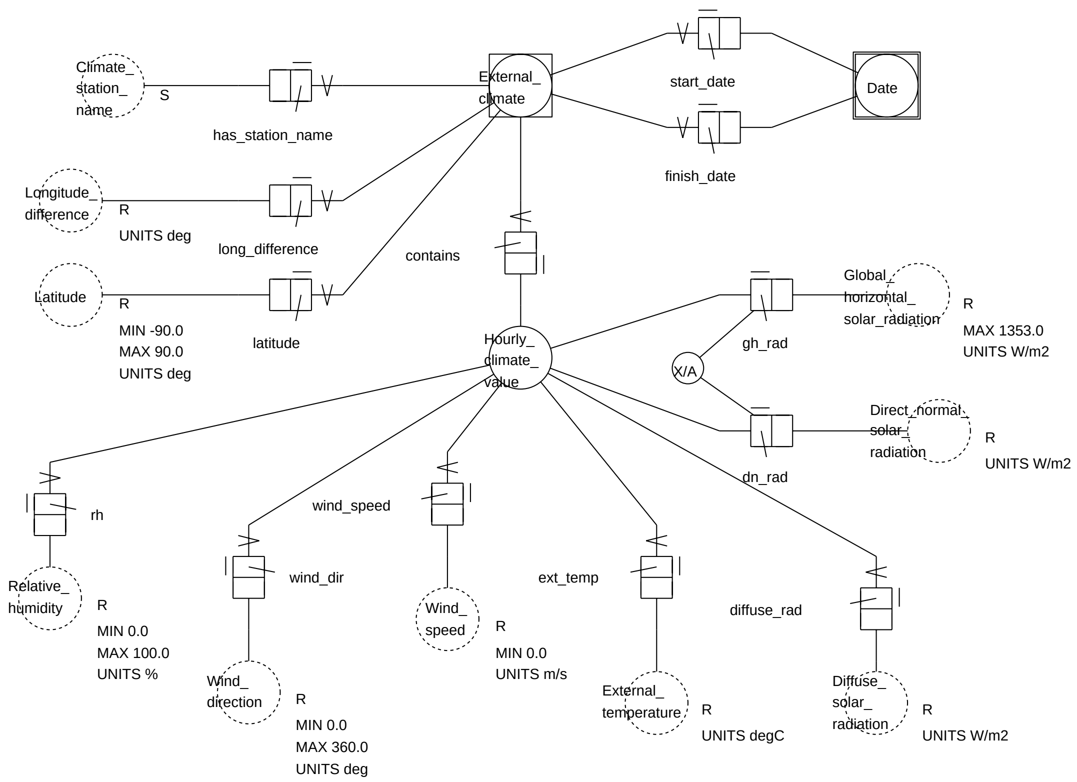

Figure 5 External_climate diagram (referenced by: ESP_r_problem).

2.5 Pressure_coefficients_database

Pressure_coefficients_database (Figure 6) contains the boundary conditions for wind-induced airflow analysis expressed as one or more sets of Pressure_coefficient (for wind impinging on the surface at 16 angles) referenced by Pressure_coefficients_database_set_number related to surfaces of particular shapes and locations.

Associated data: Each coefficient set contains 16 pressure coefficients at 16 angles (0.0°, 22.5°, 45.0°, etc). Zero degrees is external normal to surface; positive values are degrees clockwise looking from above.

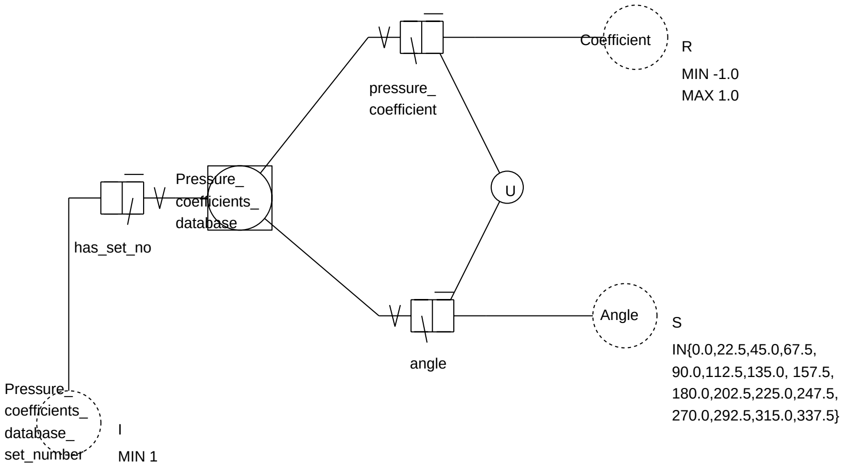

Figure 6 Pressure_coefficients_database diagram (referenced by: Problem_composition).

2.6 Ground_temperature_profile

Ground_temperature_profile (Figure 7) describes the monthly ground temperature profile which can be either a profile held within ESP-r (Internal_profile_index) or a user-specified profile (User_specified_monthly_value).

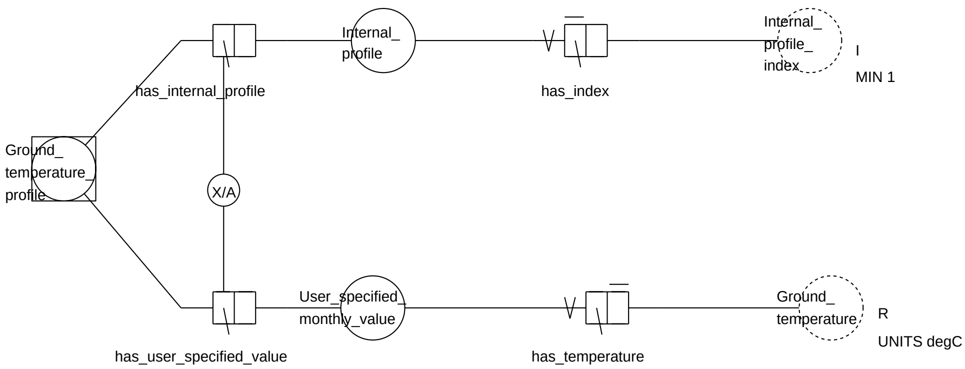

Figure 7 Ground_temperature_profile diagram (referenced by: ESP-r_problem).

2.7 Site_detail

Site_detail (Figure 8) includes the location of the building, Site_name, a Site_latitude and Longitude_difference, Ground_reflectance (assumed uniform for the site), and a Site_exposure (see Section 2.4).

Site_exposure relates to the calculation of external longwave radiation, and requires the view factors for buildings, sky and ground. They are assumed to be constant for the building. Location is expressed in terms of a string "urban_normal", "rural_normal", etc., from which an inference is made of the external view factors. Alternatively the user can specify an External_viewfactor_ distribution which comprises view factors to buildings (Building_viewfactor), sky (Sky_viewfactor) and ground (Ground_viewfactor).

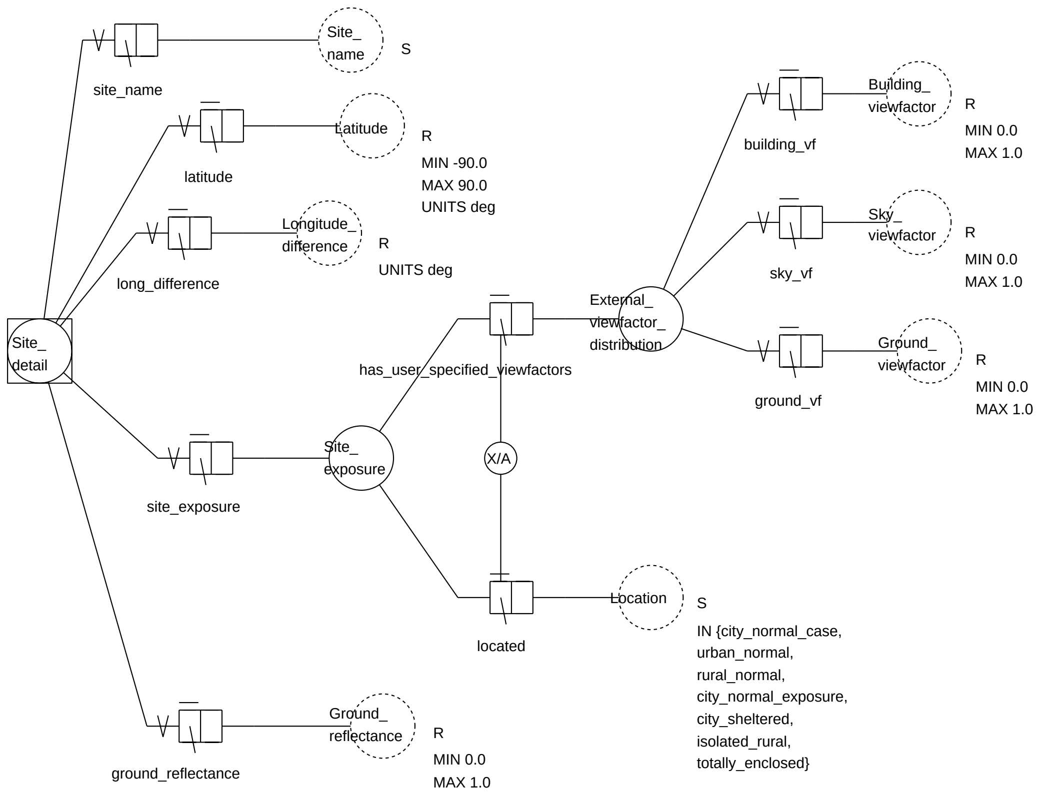

Figure 8 Site_detail diagram (referenced by: ESP-r_problem).

3 Buildings and Zones

3.1 Building

Building (Figure 9) is the highest level concept on the building side of the simulation. It includes Building_notes (related descriptions and images and project documentation), Surface_boundary_condition (contiguity properties of each surface in the model), Project_databases comprising materials, constructions, optical properties, etc. associated with the building and Zones (fundamental spaces for building simulation).

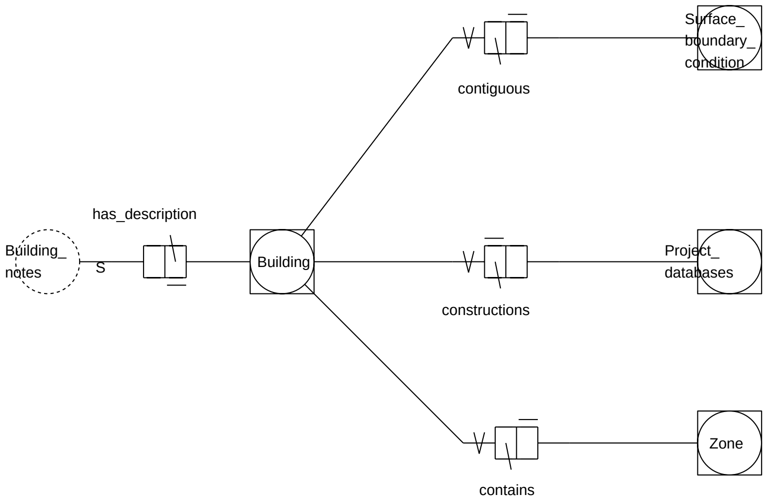

Figure 9 Building diagram (referenced by: ESP-r_problem, zone, construction_db, contiguity).

3.2 Contiguity

Contiguity (Figure 10) must be specified for each surface in each zone. The Surface_boundary_condition entity relates to the building level because it includes contiguity of zones/surfaces and supports consistency checking. It is also a surface attribute of the entity surface (see surface diagram).

Surface_boundary_condition has six mutually exclusive subtypes: External_climate (taken from the selected climate database), Relative_condition (adjacent air temperature is a Relative_air_temperature to the simulated zone), Fixed_condition (specified air temperature and incident radiation_on_surface_boundary), Contiguous_simulated_zone (adjacent conditions are another simulated zone and specified as Contiguous_zone_name and Contiguous_zone_surface_name), Ground_temperature (adjacent to a ground temperature profile), and Adiabatic (no flux transfer across the outermost boundary).

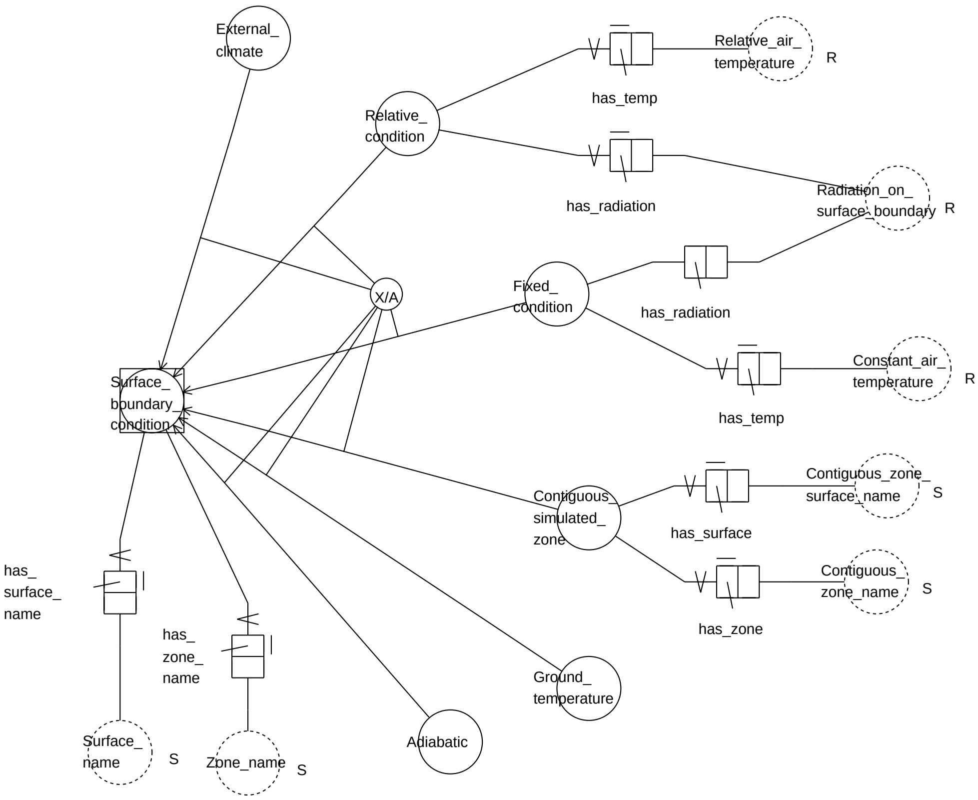

Figure 10 Contiguity diagram (referenced by: building).

3.3 Zone

Zone (Figure 11) is the fundamental space for building-side thermal simulation. Each zone contains Geometry (3-D geometrical data and references to constructional data) and Operations (details of heat gains from internal heat sources, and a simplified treatment of ventilation and infiltration heat fluxes). There are optional extra features, such as Obstruction_geom (geometric entity which shades surfaces), user-specified Convection_coefficients, and Timestep_data (measured data that can be superimposed on a simulation, either airflow data or heat gains measured time-step data). Lighting_control can also be specified at this level.

3.4 Obstruction_geom

Obstruction_geom (Figure 12) contains the 3-D representation of the obstruction geometry. It requires an Origin (3-D coordinates), Dimensions (length, width and height) and Orientation (angle to the y-axis from north, anticlockwise positive) of the obstruction block (only rectangular bodies permitted).

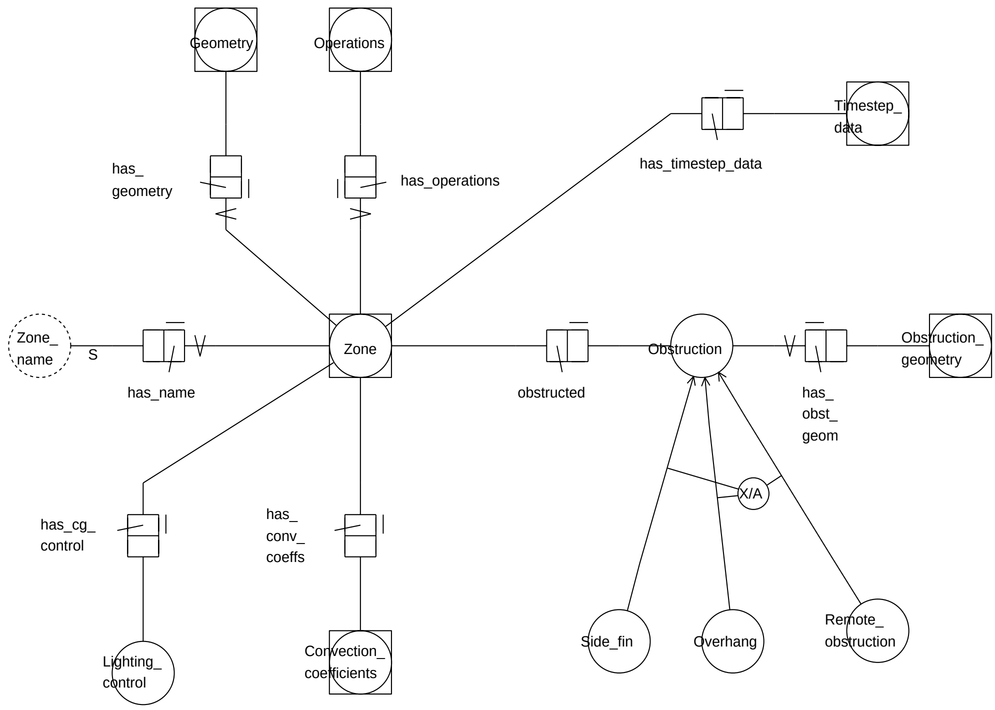

Figure 11 Zone diagram
(referenced by: building, obstruction_geom, geometry, operations).

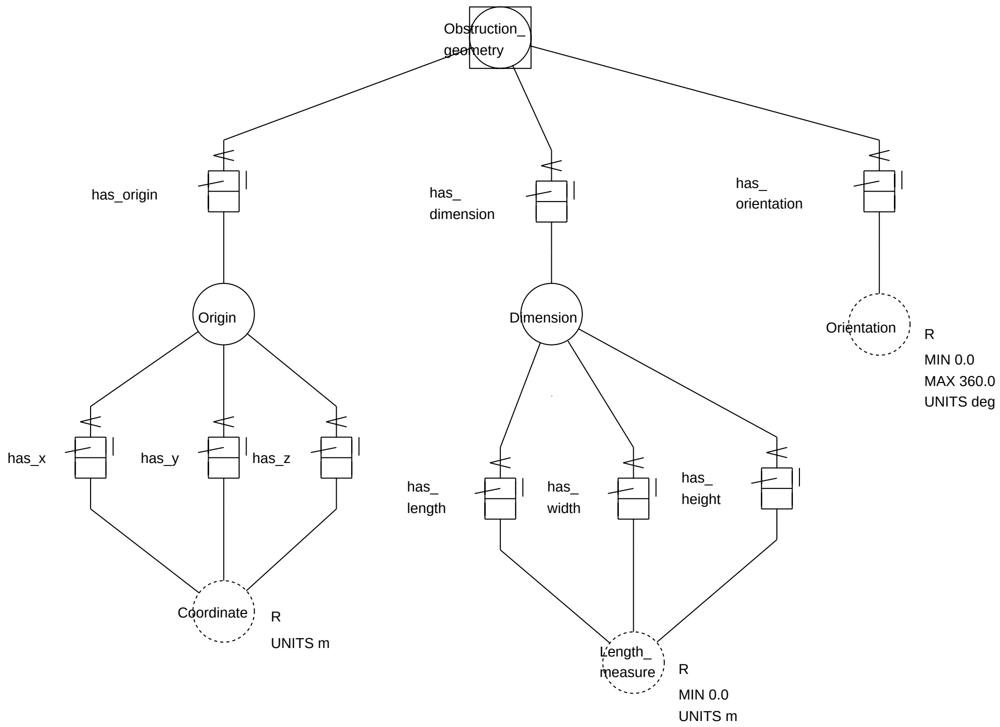

Figure 12 Obstruction_geom diagram (referenced by: zone).

3.5 Convection_coefficients

Convection_coefficients (Figure 13) can be associated with the inside and outside face of surfaces. If coefficients are not specified, ESP-r uses its internal algorithm by Alamdari and Hammond [ref] for buoyancy-driven convection for dynamic calculation of the coefficients for all surfaces. The coefficients can either be specified as fixed values (within the schedule period), or a flag (Calculated_coefficient_flag) can be given to indicate that an internal calculation of the appropriate coefficients should be made by ESP-r.

Associated data: Convection_coefficients_schedule which allows coefficients to be scheduled according to time of day.

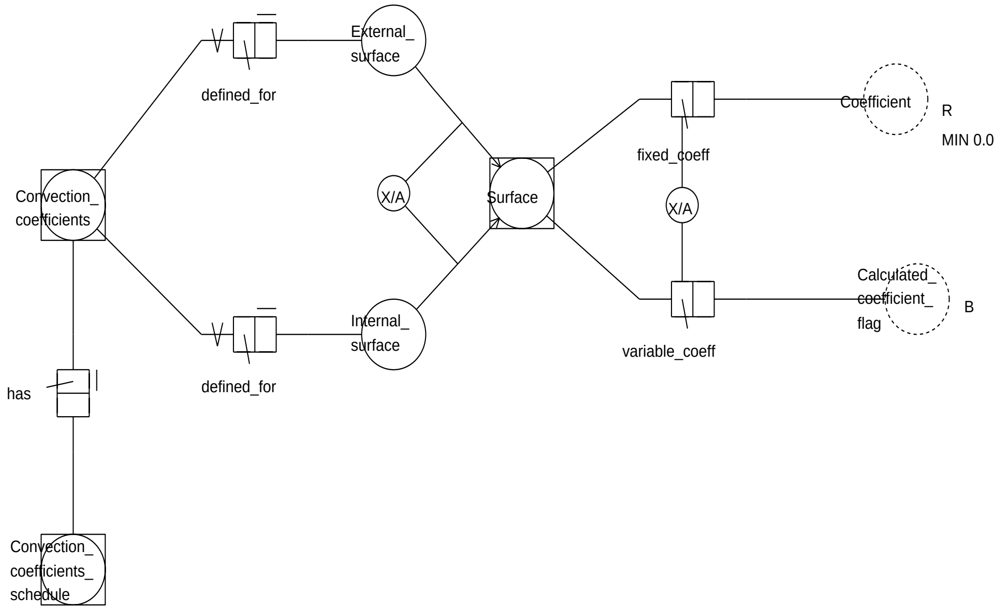

Figure 13 Convection_coefficients diagram (referenced by: zone, surface, schedule).

3.6 Timestep_data

Timestep_data (Figure 14) contains measured data that can be superimposed on a simulation, Airflow data and heat gains are subtypes. The timestep data are defined over a period between the start date and time and stop date and time. The frequency (Timestep_frequency) of the timestep data is also required and is a constant.

Associated data: Timestep_casual_gains (includes radiative, convective and latent heat gains at each timestep), Timestep_airflow (includes Zone_infiltration_rate in ac/h from outside the building, or Zone_coupled_airflow in ac/h from other zones) at each timestep.

4 Geometry

4.1 Geometry

In ESP-r there are two internal ways of specifying geometry. The basic form (Figure 15) is a Geometry-shape of subtypes General (GEN) body or Rectangular (REC) bodies (obstructions and visual entities).

Rectangular subtype defines a box. The coordinates of the origin (3D coordinate) and the length (in the x-coordinate direction), width (in the y-coordinate direction), height (in the z-coordinate direction) and orientation (angle to the y-axis from north, anticlockwise positive) are required.

General subtype defines a polygon bounded enclosure. In this case the vertices (x,y, and z coordinates) of the zone are input and linked as an ordered list (anticlockwise looking from outside the zone) to define polygon edges.

Associated data: Bounding_vertex is a linked list of vertex indices which define a surface. The geometry of each zone is composed of a number of surfaces. The Surface entity contains information on attributes related to surfaces.

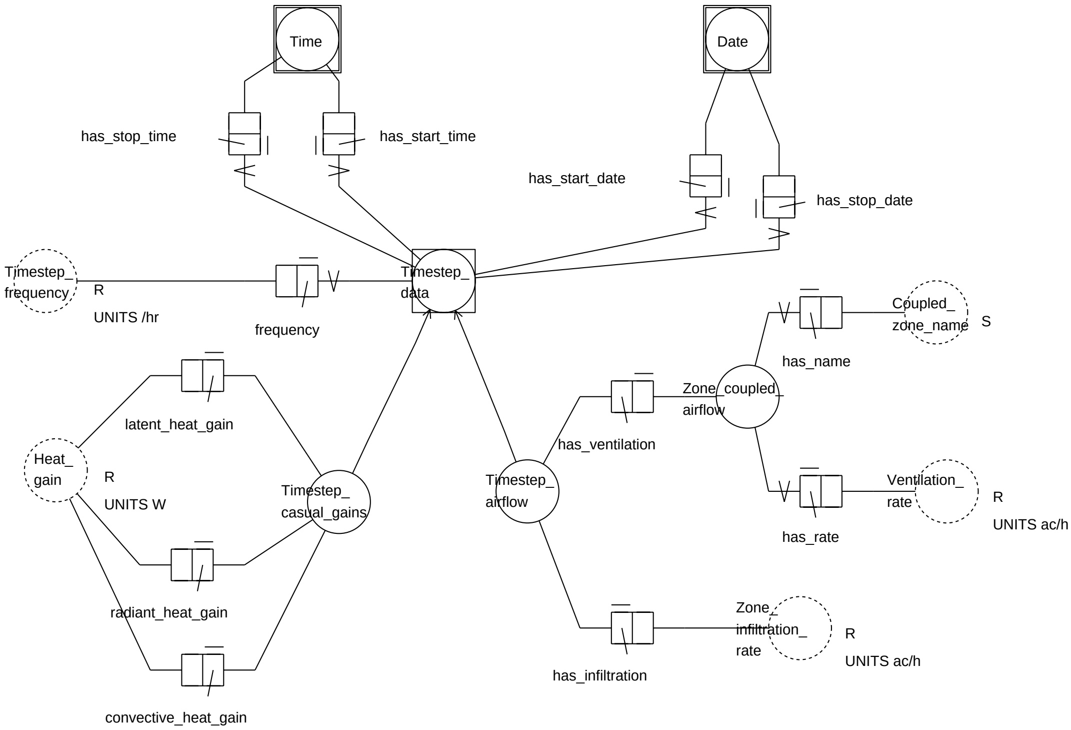

Figure 14 Timestep diagram (referenced by: zone).

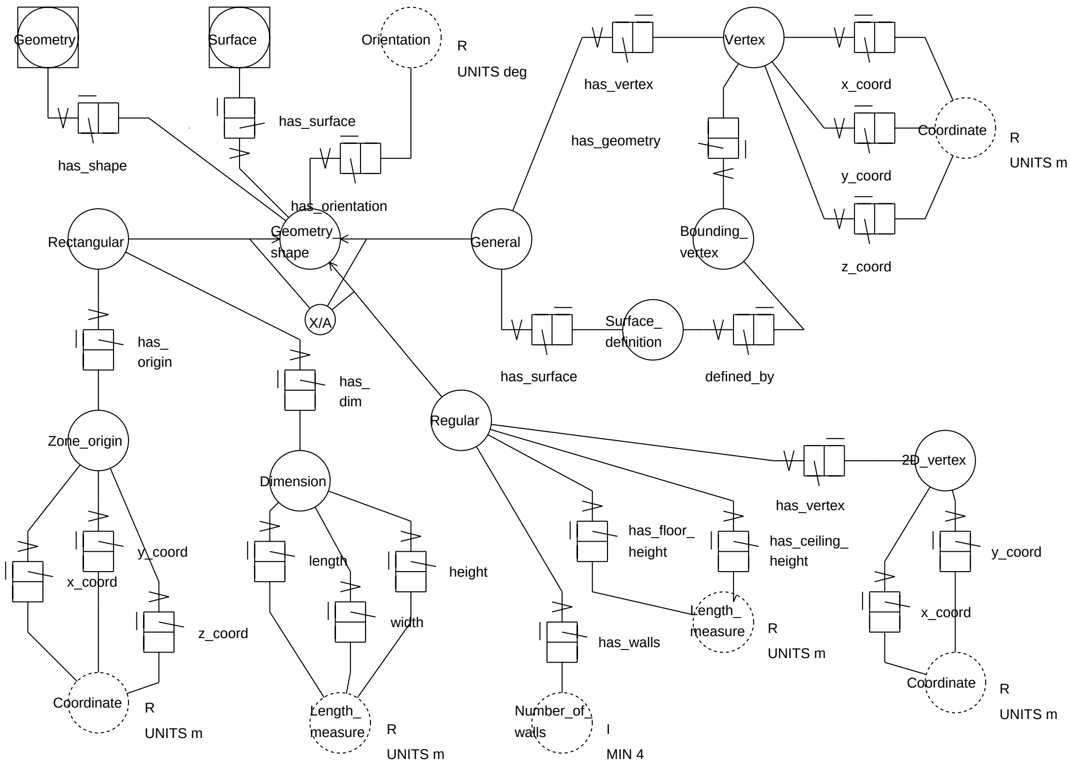

Figure 15 Geometry diagram (referenced by: zone, surface).

4.2 Surface

Surface (Figure 16) contains information on surface attributes (e.g. Surface_name, Construction_name (reference to the entry in the constructional database) and Boundary_condition) which must be specified.

Boundary_condition supports the variants (exterior, similar, fixed, contiguous_zone, ground, adiabatic). These choices are decomposed in the contiguity diagram (section 2.2) and are merely referenced here.

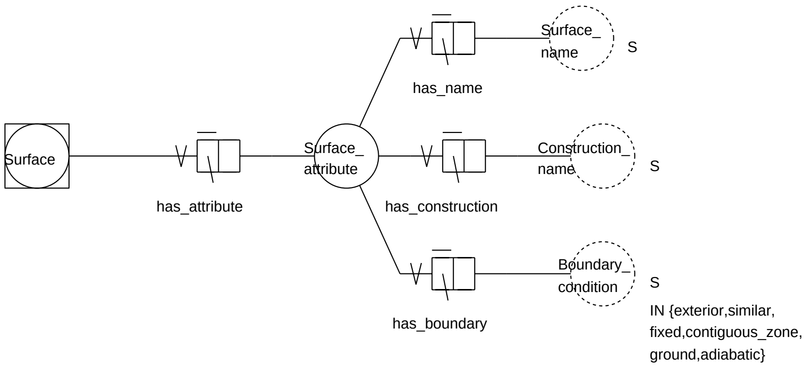

Figure 16 Surface diagram (referenced by: geometry).

5 Construction

Constructional properties have been decomposed using the Construction_database, which contains the thermophysical properties of all constructions within the building. There is also a reference on the surface diagram to the Construction_name (i.e. database entry) attribute associated with each surface.

5.1 Construction_database

Construction_database (Figure 17) is linked to the Building entity, so there is one Construction_database_name for each project. Construction contains the entries in the database.

Materials_database contains the details of the individual Materials (basic thermophysical properties) from which constructions are composed. One Materials_database_name is associated with the project.

Optical_database contains the optical properties for transparent surfaces and is referenced by the Construction_database.

Glazing denotes the optical properties of each type of glazing held in the Optical_database.

5.2 Construction

Construction (Figure 18) contains the details of an individual construction (Construction_name, Glazing (optical properties for transparent constructions), Layer (construction comprises one or more layers of Material or Air), Thickness (of each layer), Material (homogeneous material comprising the layer) held in the Construction_database.

Material (Figure 19) contains the thermophysical properties of materials used in constructions (Material_name, Conductivity, Density, Specific_heat, Short_wave_surface_absorptivity, Long_wave_emissivity, Moisture_diffusion_resistance). All are compulsory except Moisture_diffusion_resistance which is used only for moisture calculations.

Associated data: Air is treated differently from other materials. Air_gap_resistance is an attribute of the construction with thermal resistance values for vertical, horizontal and sloped surface orientations.

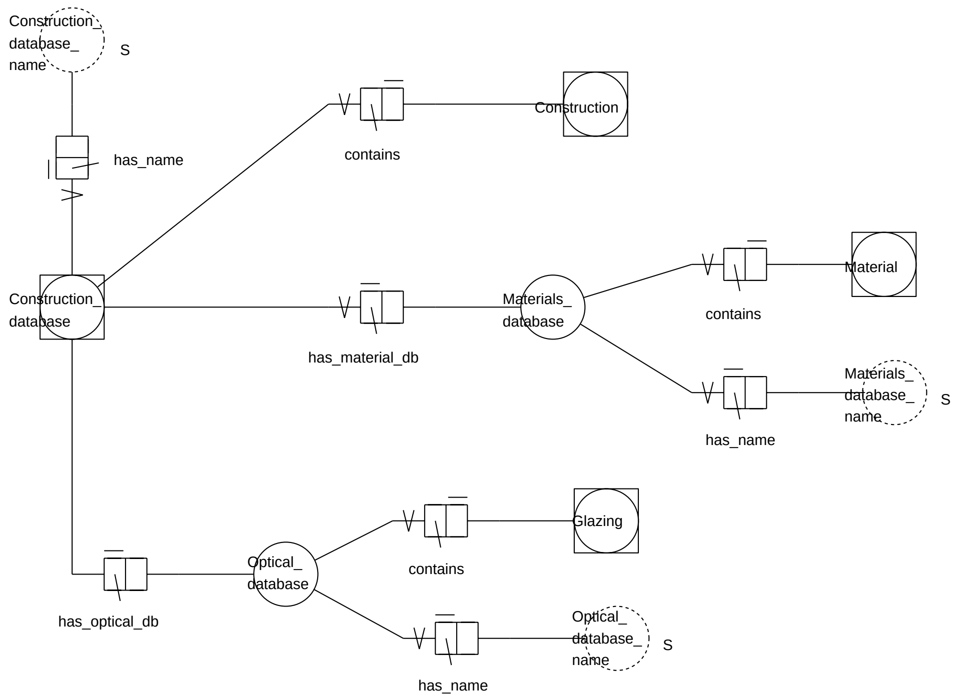

Figure 17 Construction_database diagram (referenced by: building).

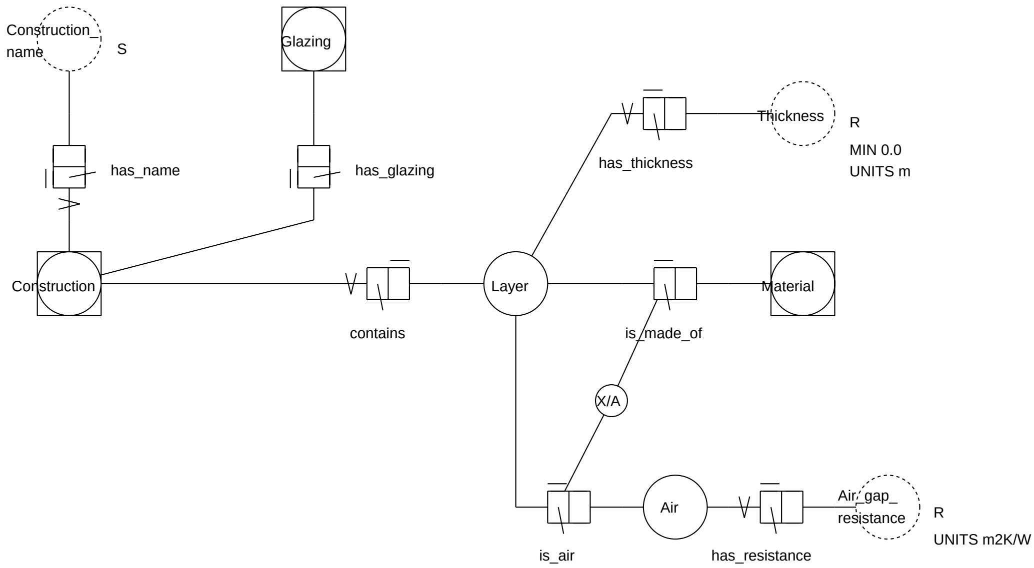

Figure 18 Construction diagram (referenced by: construction_database, material, glazing).

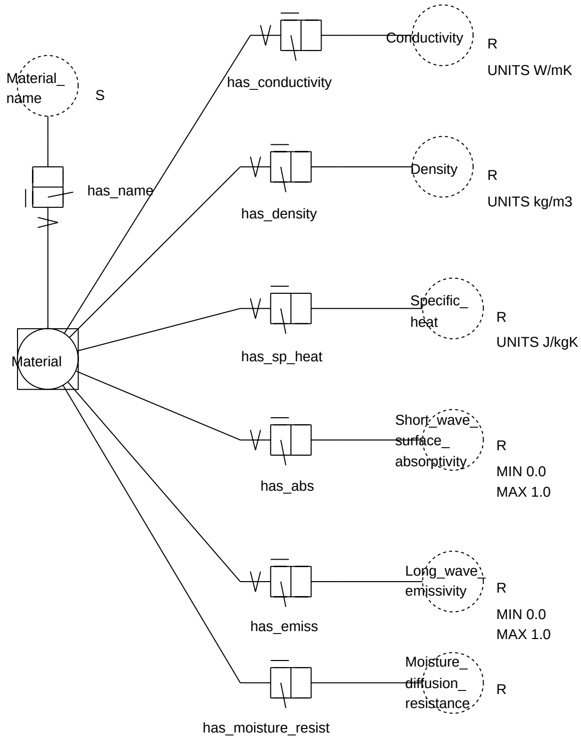

Figure 19 Material diagram (referenced by: construction).

5.3 Transparency

As mentioned in the geometry decomposition, glazing systems are surfaces which are given Transparency attribute and have as one attribute a set of optical properties. Optical requirements are the system direct transmission and the solar absorptivity (at several angles of incidence) of each layer in the transparent system obtained from entries in the optical database.

Glazing (Figure 20) contains standard optical properties (Standard_properties) for transparent constructions. It can also have a schedule for varying glazing properties (Replacement_properties) according to time, incident solar radiation or external temperature. Within the schedule (Glazing_properties_schedule) there is a possibility of control based on some activation level. This is expressed through Standard_properties and Replacement_properties as subtypes of Glazing.

Sensor_type: Within each schedule period, control can be effected by radiation sensors (Radiation_sensor) or external temperature sensors (External_temperature_sensor).

Activation_point_temp must be specified - if the activation point is exceeded, Replacement_properties are used. If not, the Standard_properties are used.

Activation_point_rad must be specified - if the activation point is exceeded, Replacement_properties are used. If not, the Standard_properties are used.

Associated data: A Surface_name is given if the sensor is associated with a particular surface, otherwise it applies to all.

5.4 Glazing_properties

Glazing_properties (Figure 21) have subtypes Direct_transmittance and Absorptivity. Values for each of these subtypes are required at five angles of incidence (0, 40, 55, 70 and 80 degrees).

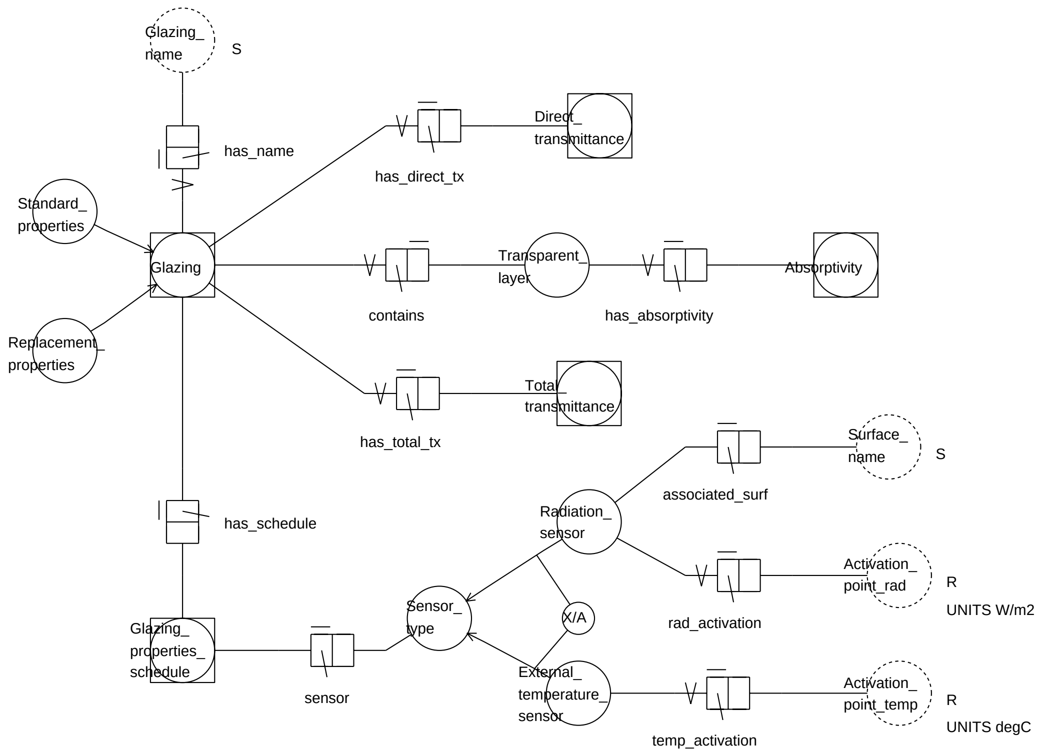

Figure 20 Glazing diagram (referenced by: constructions, glazing_properties).

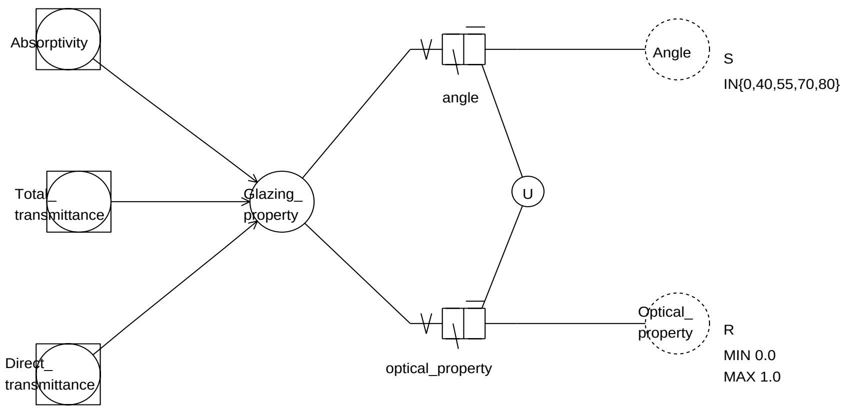

Figure 21 Glazing property diagram (referenced by: glazing).

6 Operations

Operations in ESP-r are for airflow (an alternative to the network model) and for internal heat gains by occupants, lighting and equipment. Operations_airflow and Operations_casual gains are subtypes shown in Figure 22.

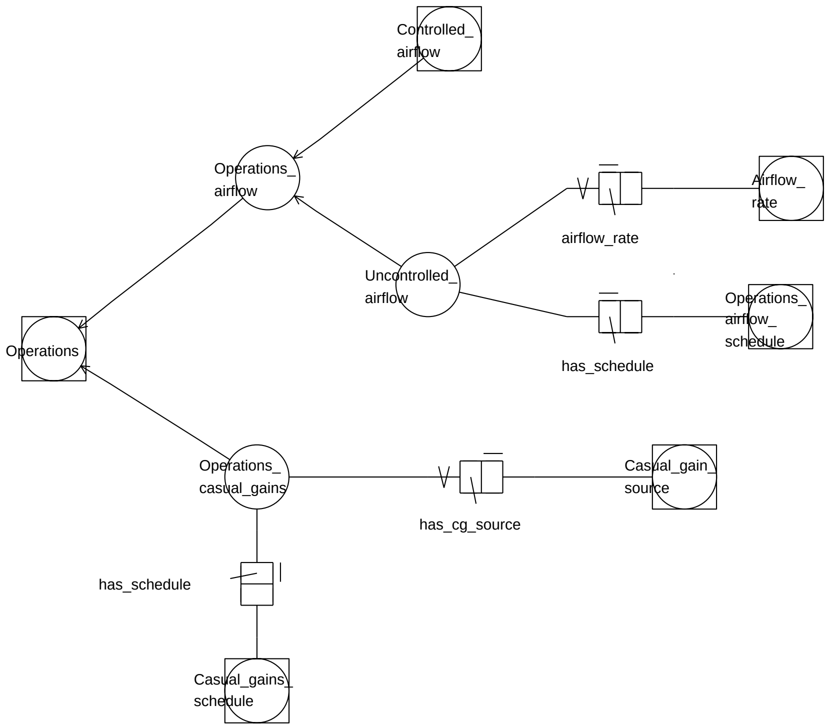

Figure 22 Operations diagram
(referenced by: zone, casgains_sourec, airflow_rate, controlled_airflow,schedule).

6.1 Operations_casual_gains

Operations_casual_gains are composed of one or more Casual_gain_source (Figure 23). Both can be scheduled differently on weekdays, Saturdays and Sundays. For airflow it is also possible to have thermostatic control based on range of control conditions.

Associated data: Casual_gains_schedule allows a day type (Daytype_wss) to be associated with an Operation. Each casual gain has a convective and radiant fraction (Rad_conv_fraction) the sum of which should not exceed 1.0. In the case of Floor_area_per_occupant, casual gains assume a heat gain per person of 95W sensible, 45W latent.

Casual_gain_source indicates the possible sources (Occupant_heat_gain, Equipment_heat_gain, Lighting_heat_gain, Lighting_heat_gain_per_unit_floor_area, Heat_gain_per_unit_floor_area, Equipment_heat_gain_per_unit_floor_area, Occupant_density) of internal heat gains.

6.2 Operations_airflow

Operations_airflow includes two subtypes Uncontrolled_airflow (scheduled fixed flow) and Controlled_airflow (responds to some control variable). Airflow_rate consists of the infiltration and ventilation air flows.

Controlled_airflow (Figure 24) allows the airflow to be based on time-dependent zone air temperatures or ambient conditions. The possibilities are quite extensive. Often, however, it may be more appropriate to model complex control using an airflow network with an associated control. Control will depend on the value of some control variable and will be associated with controlled airflow rates. It has three subtypes, Zone_coupled_only, Infiltration_only, and Zone_coupled_and_infiltration.

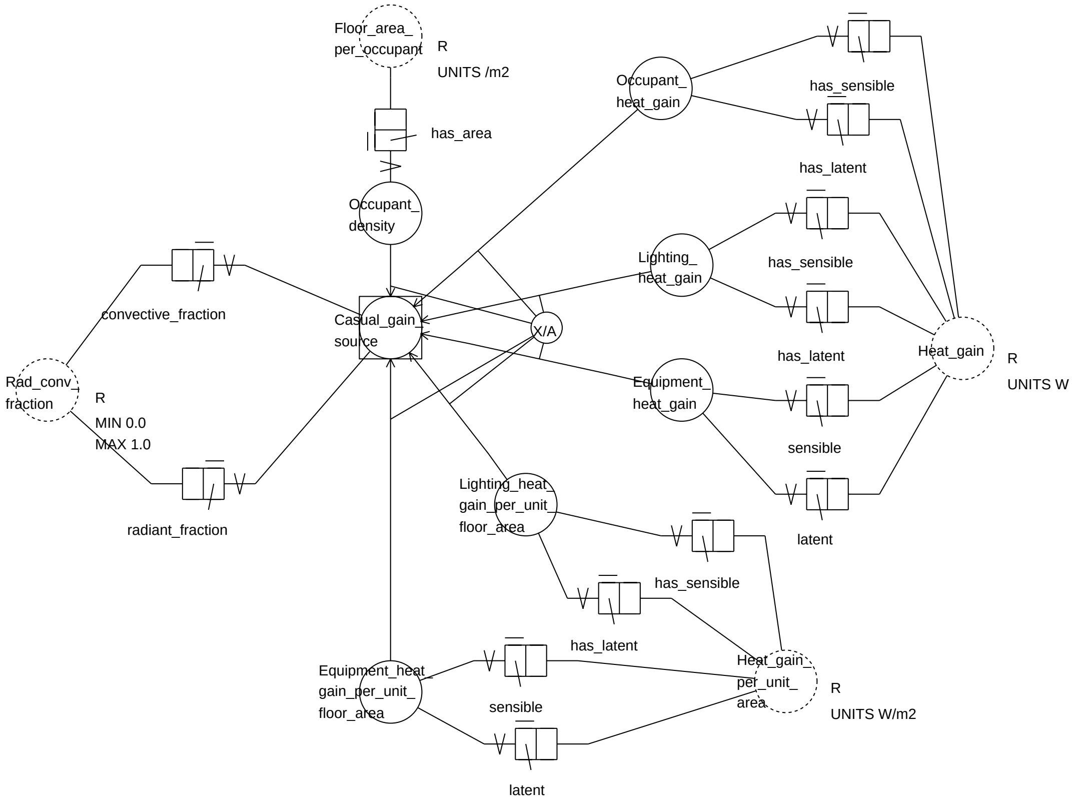

Figure 23 Casual_gain_source diagram (referenced by: operations).

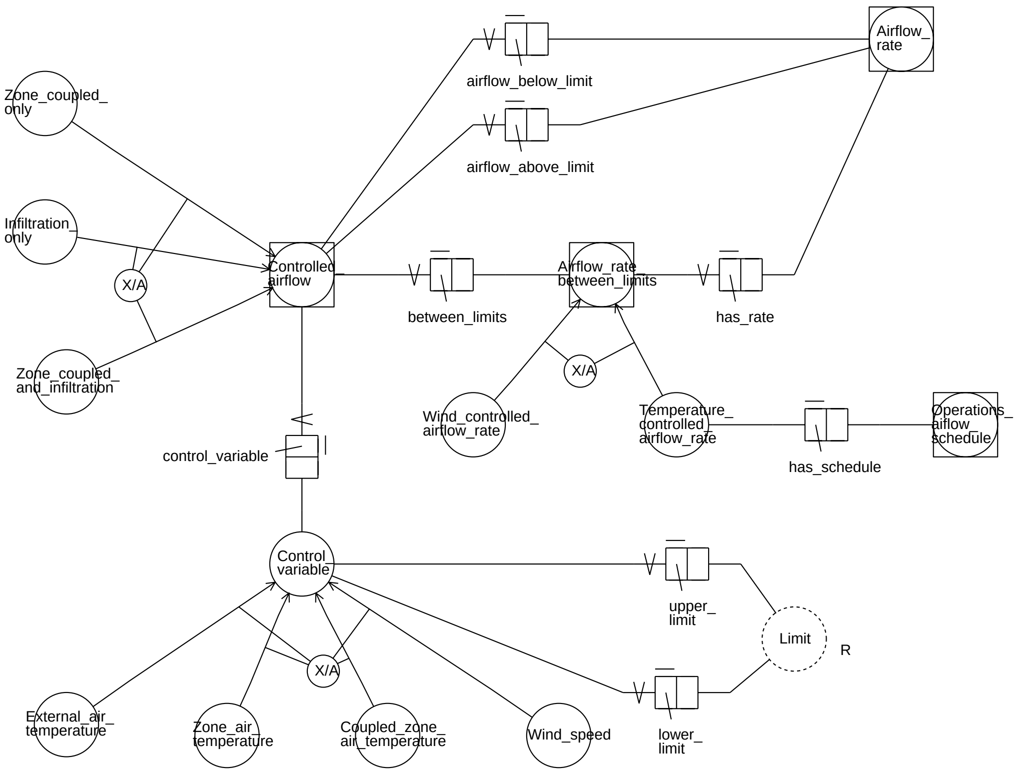

Figure 24 Controlled_airflow diagram (referenced by: operations).

Control_variable values are of type External_air_temperature, Zone_air_temperature, Coupled_zone_air_temperature, Wind_speed each of which has an upper and lower limit.

Airflow_rate is dependent on the control variable. There are four possibilities: above, below, between the limits and a second stage rate. If above or below, fixed airflow rates are used. If between, they can be scheduled.

Airflow_rate_between_limits allows scheduling possibilities and includes two subtypes, depending on whether the control variable is Temperature_controlled_airflow_rate (allows scheduled and controlled flow as described above) or Wind_controlled_airflow_rate (proportional control between a lower limit of zero wind speed and a user-defined upper limit).

6.3 Airflow_rate

Airflow_rate (Figure 25) is composed of two types: Infiltration_air_change_rate (ac/h from outside the building at the external air temperature) and Zone_coupled_air_change (ventilation in ac/h from another zone or at a fixed temperature and flow rate).

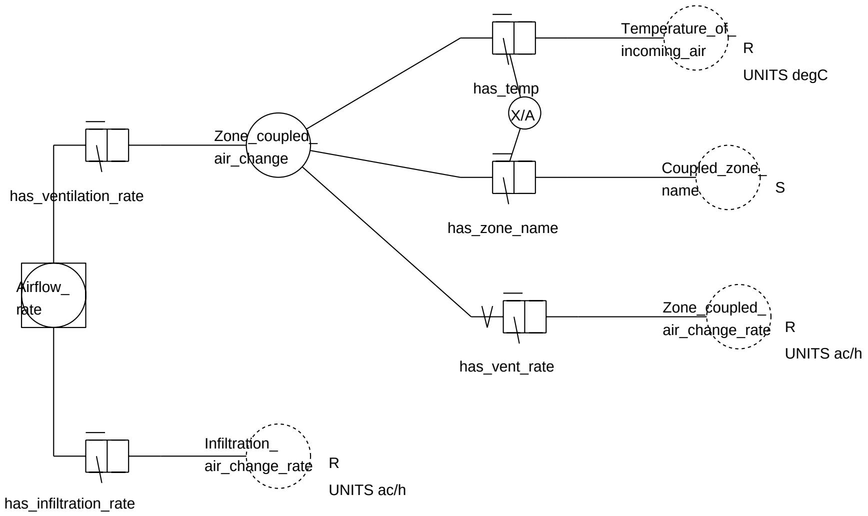

Figure 25 Airflow_rate diagram (referenced by: operations, controlled_airflow).

7 Schedule

Scheduling is possible for many of the functions within ESP-r. These have been added to the relevant parts of the decomposition. However, all scheduling has been brought together within the schedule ATLIAM diagram.

7.1 Schedule

Schedule (Figure 26) is a supertype of all schedules in ESP-r. It can have one or more schedule periods which divide up a day. If there are no schedule periods, it is assumed that the control is active for all 24 hours of the day. Current schedule types are: Convection_coefficients_schedule, Glazing_properties_schedule, Operations_airflow_schedule (with the possibility of different controls being possible on weekdays, Saturdays and Sundays).

Building_control_schedule is a subtype which can have dates of validity, as well as day types (weekday, Saturday, Sunday).

Flow_control_schedule is a subtype which offers the same possibilities as building control.

Casual_gains_schedule is a subtype which can have a day type associated, and different controls possible on weekdays, Saturdays and Sundays.

Schedule_period(s) divide up a day, and have one or more start and stop times. The control will be active from the first timestep after the start time to the first timestep after the stop time. To schedule all 24 hours, the start and stop times would be 00.00 and 24.00 respectively.

Dates_of_validity are applicable to building and flow control schedules to allow different building control for different seasons (or indeed different weeks or even days). If not specified control is active for every day of the year.

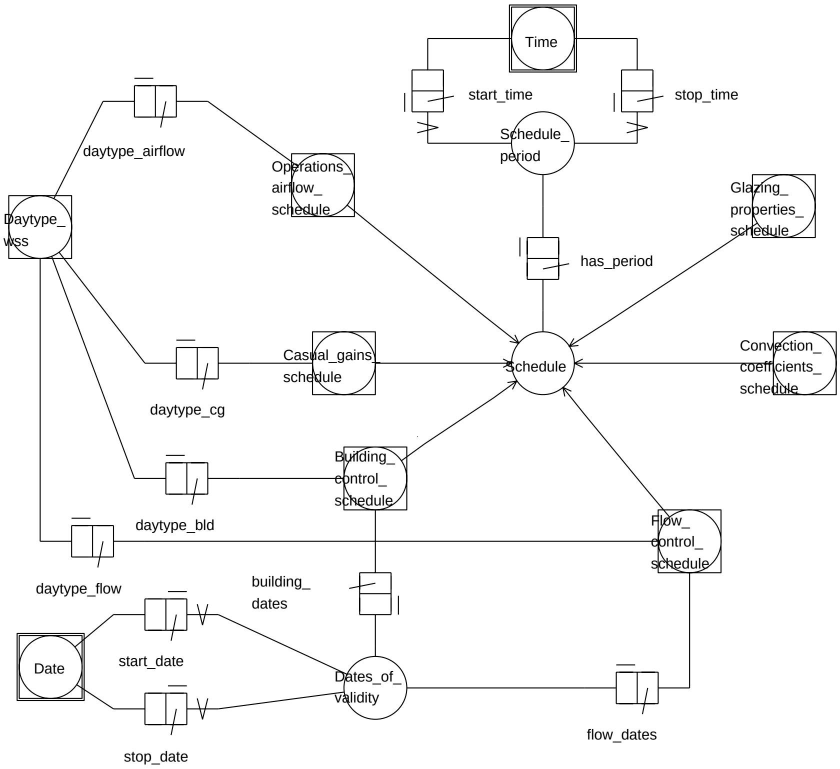

Figure 26 Schedule diagram.

7.2 Daytype_wss

Daytype_wss (Figure 27) relates to operations schedules and supports different schedules on weekdays (Daytype_weekday), Saturdays (Daytype_saturday) and Sundays (Daytype_sunday). It is not possible to have a different schedule on Monday and Tuesday).

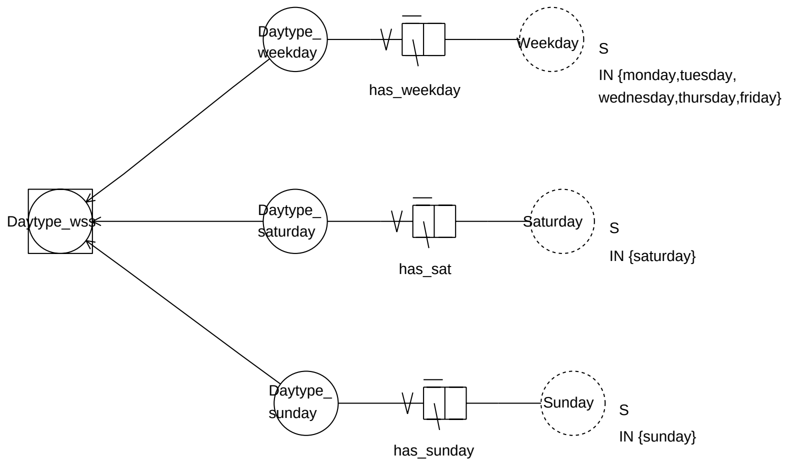

Figure 27 Daytype_wss diagram (referenced by: schedule).

8 Building Control

This section gives details on the building control decomposition. Some of the more esoteric control options have not been decomposed here (see Figure 32 for all the building control law options).

8.1 Building_control

Building_control (Figure 28) is the highest level diagram for building control. It contains references to Sensor_point (location of the sensor), Actuator_control_point (location of the actuation control point), control types and laws which can be attached to one or more zones.
Building_control_schedule is a subtype of schedule (see Section 7) with the exception that sensor and actuation control points are fixed for any given Building_control.

Control_type determines the properties that are sensed and actuated.

Control_law specifies the control algorithms representing the logic of some, real or imaginary, controller.

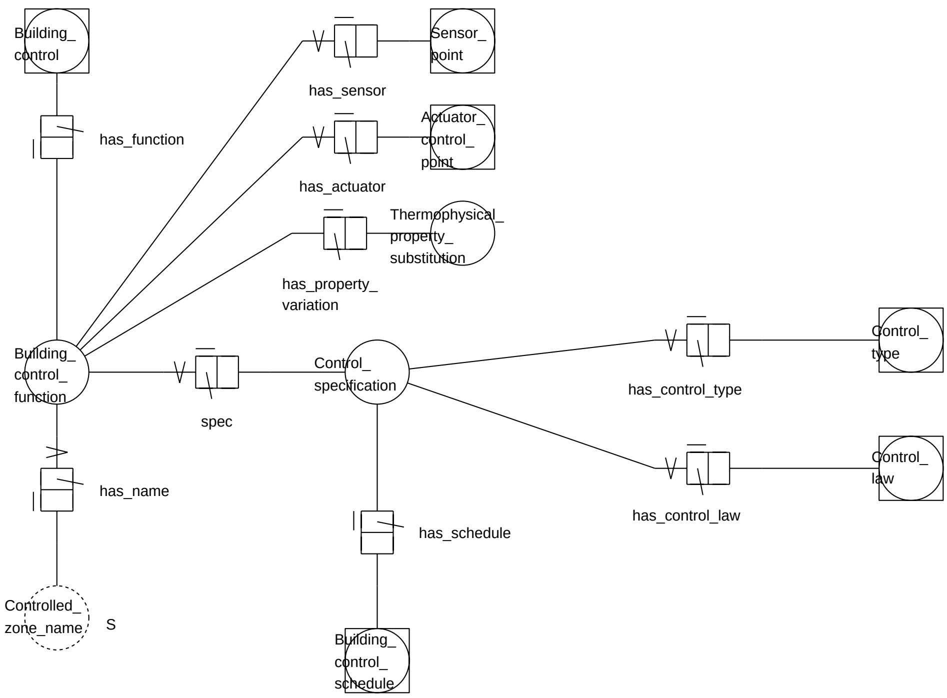

Figure 28 Building_control diagram (referenced by: ESP_r_problem, schedule).

8.2 Sensor_point

Sensor_point (Figure 29) includes several variants: Zone_temperature_sensor (dry bulb temperature), Air_temperature_sensor (external temperature from the climate database), Surface_temperature_sensor (inside or outside face), Intra_construction_temperature_sensor, Mixed_conv_rad_sensor (mix of mean radiant temperature and the air temperature) and Sol_air_temperature (subtype of Sensor_point based on this derived value).

Associated data: Convective_weighting_factor is the proportion of convective input (the remainder is assumed to be radiative).

8.3 Actuator_control_point

Actuator_control_point (Figure 30) defines possible locations for the point of control actuation. It has several subtypes: Zone_temperature_control_point (convective injection), Intra_construction_temperature_control_point (injection within a construction), Mixed_conv_rad_control_point (a mixed convection to the air and radiant injection to inside face of all surfaces).

Plant_component_actuator is a subtype of Actuator_control_point. This entity is part of plant system modelling and has not been decomposed here.

Associated data: Convective_weighting_factor (as above).

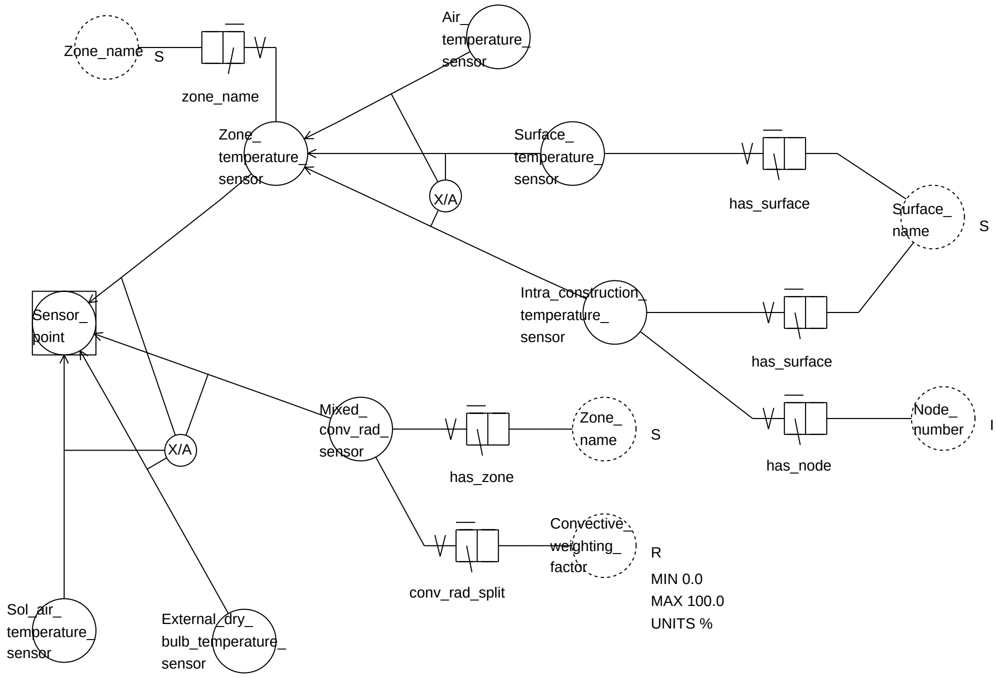

Figure 29 Sensor diagram (referenced by: building_control).

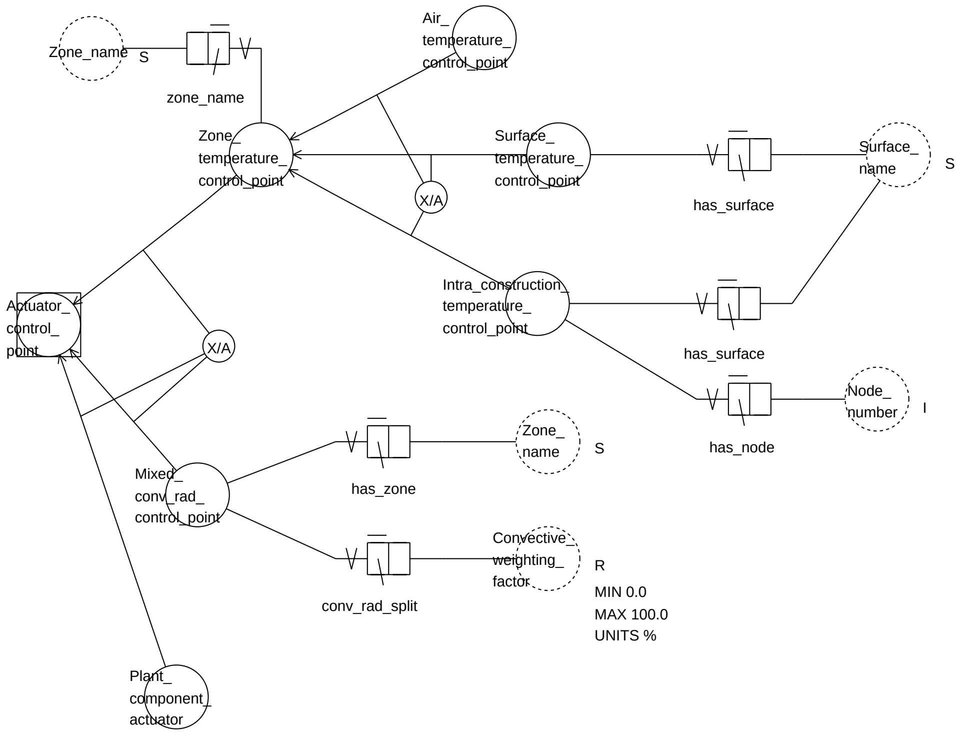

Figure 30 Actuator_control_point diagram (referenced by: building_control).

8.4 Control_type

Control_type (Figure 31) is a subschema showing the possibilities for control properties within the building-side simulation. Control_type consists of Sensed_property (temperature in the case of building) and Actuated_property (flux in the case of building).

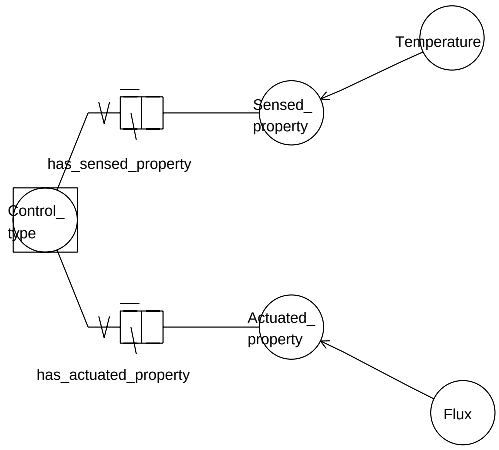

Figure 31 Control_type diagram (referenced by: building_control).

8.5 Control_law

Control_law (Figure 32) is a superset of the building-side control laws. The more common laws are: Ideal_control, Free_float_control (effectively "no control"), Ideal_preheat_precool, Ideal_fixed_heat_injection, PID_control, Multi_stage_control_with_hysteresis, Variable_supply_temperature_control, Time_proportioning_on_off_control.

Ideal_control (Figure 33) causes the sensed condition to attain a specified set-point within the limitations of specified heating and cooling flux limits.

Additional data: Plant_capacity (heating and cooling maximum and minimum values) and Setpoint_temperature (heating and cooling).

Ideal_preheat (Figure 34) causes an exponential evolution of the control variable to a specified set-point throughout the scheduled period.

Additional data: Plant_capacity (heating and cooling maximum and minimum values) and Setpoint_temperature (heating and cooling).

Ideal_fixed (Figure 35) causes an injection of a specified heating flux as a convective input, if the temperature falls below the heating set point. Cooling is treated similarly.

Additional data: Flux_injection (Fixed power) and Actuation_temperature (heating and cooling).

PID_control (Figure 36) emulates of PID controllers. Subtypes of PID_control are: P_control (proportional control only), PI_control (proportional and integral control only), PD_control (proportional and differential control only), Full_PID_control (proportional, integral and differential control).

Additional data: Derivative_action_time, Integral_action_time, Plant_capacity (heating and cooling maximum and minimum values), Setpoint_temperature (heating and cooling) and Throttling_range (for proportional control).

Multistage_control_with_hysteresis (Figure 37) emulates a control providing several stages of heating and cooling. Increasing levels are used to reach temperatures within a specified deadband which is centred on the specified set-point temperature.

Associated data: Flux_injection (at each stage of the control, heating and cooling), Setpoint_temperature (heating and cooling), and Deadband (heating and cooling).

Var_supply_temp_control (Figure 38) emulates a variable supply temperature system with limit constraints. Supply temperature is calculated given a fixed air volume flow rate in order to attain the set-point temperature (if limits allow).

Additional data: Supply_air_temperature (maximum and minimum values), Air_volume_flow_rate (fixed flow rate), Setpoint_temperature (heating and cooling) and a Cooling_availability_flag (to indicate if cooling is available in addition to heating).

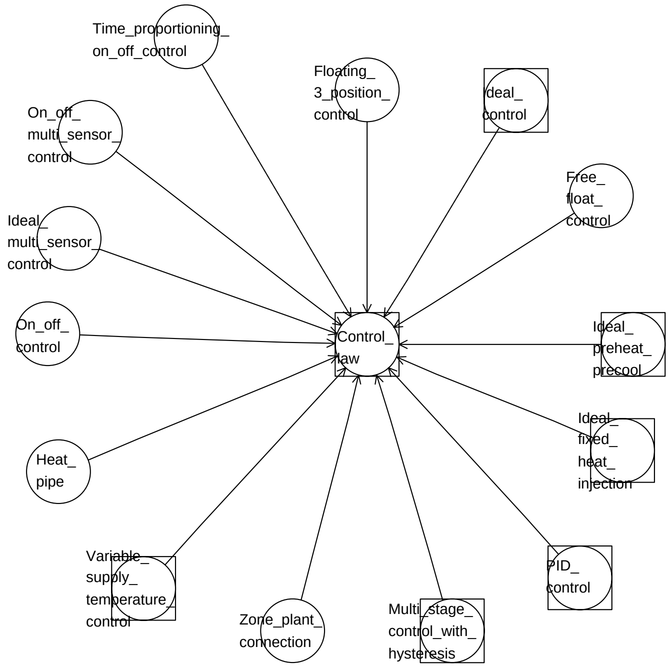

Figure 32 Control_law diagram (referenced by: building_control).

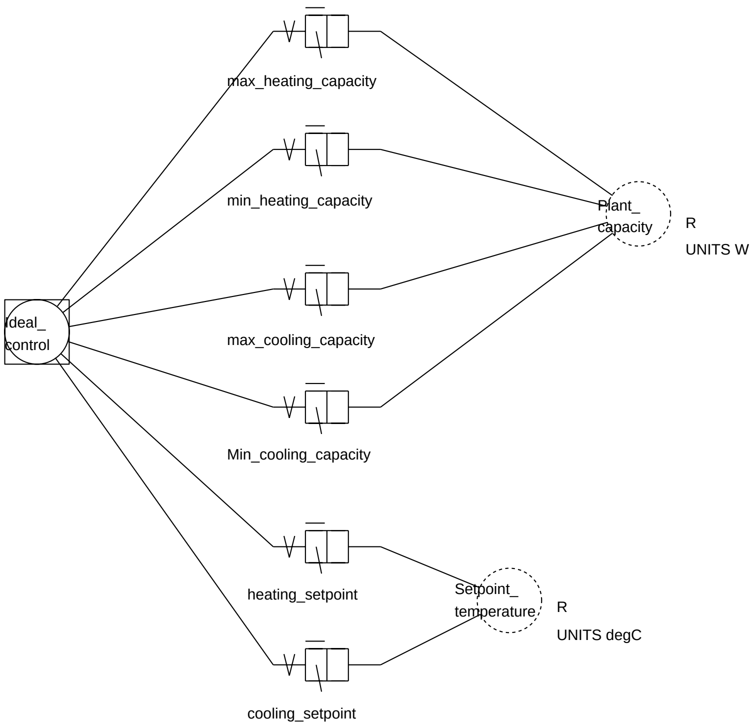

Figure 33 Ideal_control diagram (referenced by: control_law).

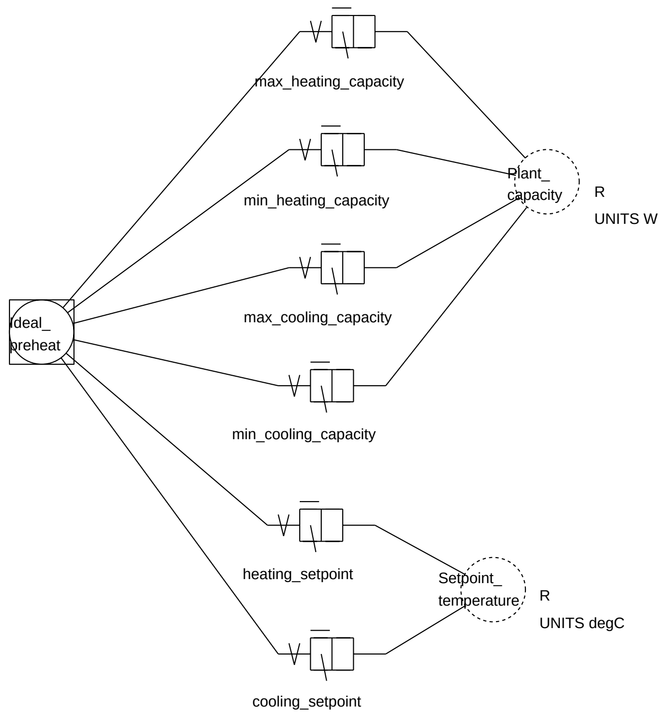

Figure 34 Ideal_preheat diagram (referenced by: control_law).

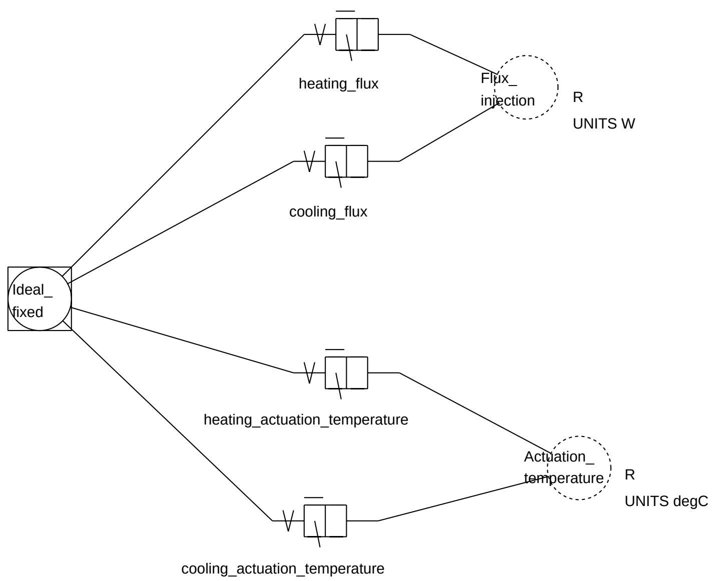

Figure 35 Ideal_fixed diagram (referenced by: control_law).

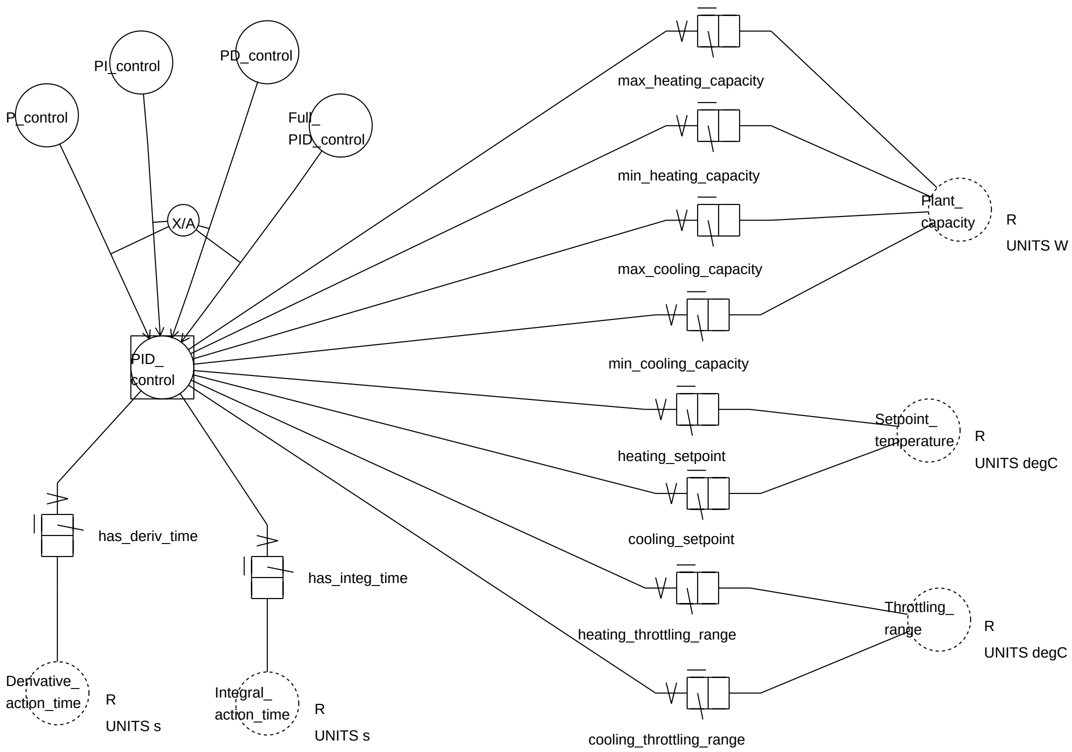

Figure 36 PID_control diagram (referenced by: control_law).

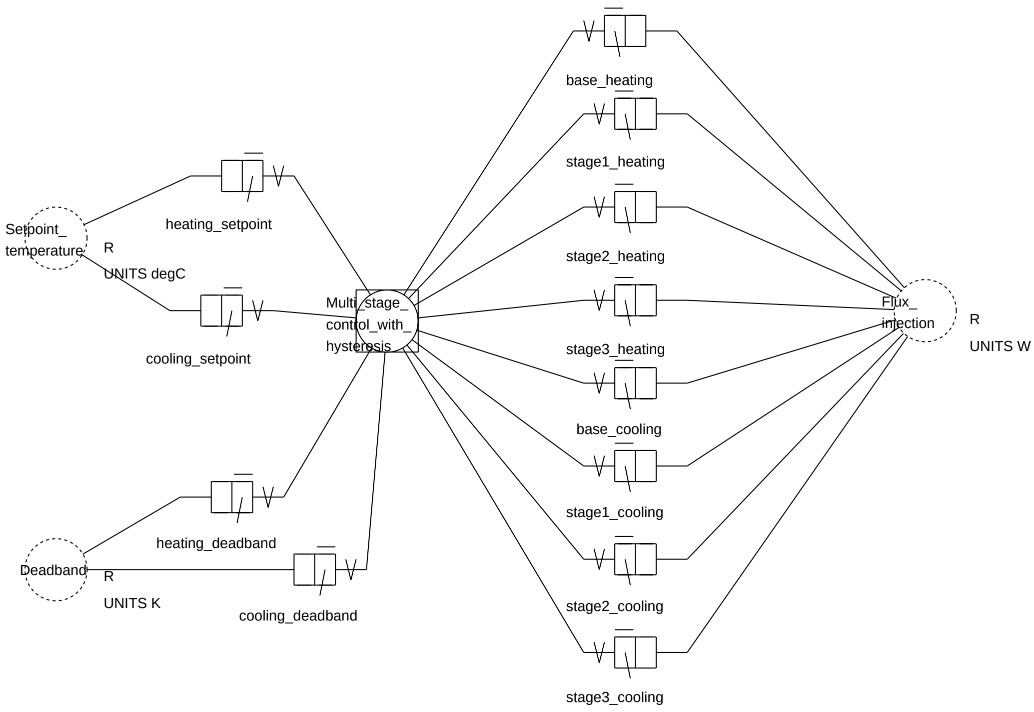

Figure 37 Multistage_control diagram (referenced by: control_law).

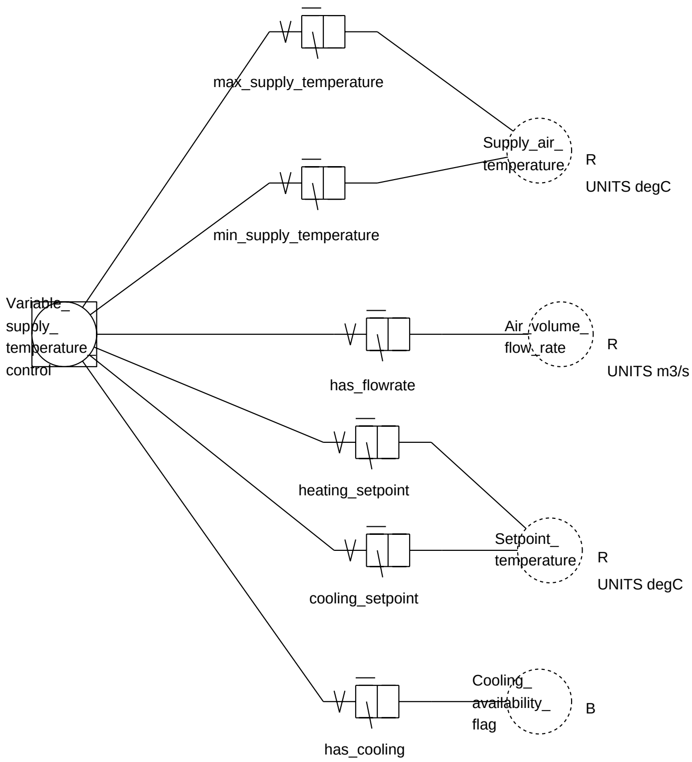

Figure 38 Var_supply diagram (referenced by: control_law).

9 Outputs

The possible outputs from ESP-r as a thermal performance evaluation tool can be grouped into building properties, model attribution and performance assessment (see Figure 2). Although models are often considered as input schema, ESP-r can be used to add attributions (e.g. to raw CAD data) for export to other tools. The other outputs, building properties and performance assessment are described in this section.

9.1 Performance_assessment

Performance_assessment (Figure 39) has been decomposed into three subtypes:

Principal_parameter_data is the raw timestep data of temperatures, flows and fluxes. These can be given for any node within ESP-r's discretized system.

Derived_performance_data relates to commonly asked thermal design questions, such as energy consumption, plant sizing, comfort conditions, overheating risk etc.

Parameter_distribution_data Each of the temperatures, flows and fluxes can also be expressed in terms of their distribution (e.g. temperature profile through a construction, shortwave distribution within a zone).

Associated data: Zone_name holds the names of the zone(s) or "all" for the scope of the analysis reporting and Start_period and End_period define the period of analysis.

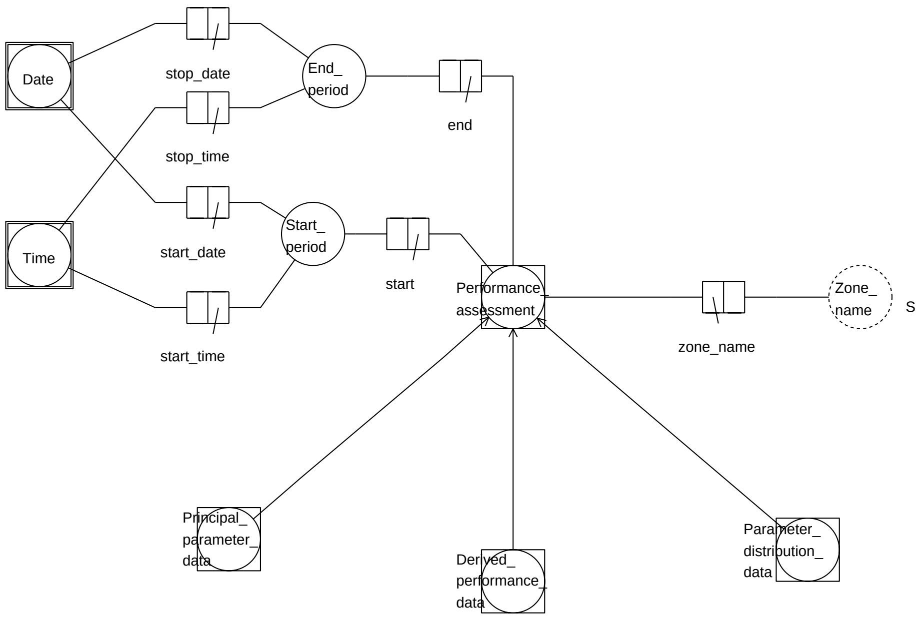

Figure 39 Performance_Assessment diagram (referenced by: ESP_r).

9.2 Principal_parameters

Principal_parameters (Figure 40) are raw timestep temperatures, flows and fluxes. Subtypes are Zone_data, Surface_data, Intra-constructional_data and Flow_data. These can be expressed in several forms: Summary_data (i.e. maximum, minimum and mean values over the analysis period) or Timestep_data (data exported at the simulation timestep, or averaged over specified time-steps).

Zone_data consists of temperatures, fluxes (from heating, cooling, ventilation and infiltration) and relative humidity relating to the air in the zone.

Surface_data consists of the fluxes (convective, longwave and shortwave radiative, and conductive), together with surface temperature. It also contains a reference to the surface name and a surface index to indicate internal or external surface.

Associated data: Surface_index (position in list), Intra_constructional_data (data within the constructions) and Node (position within a construction).

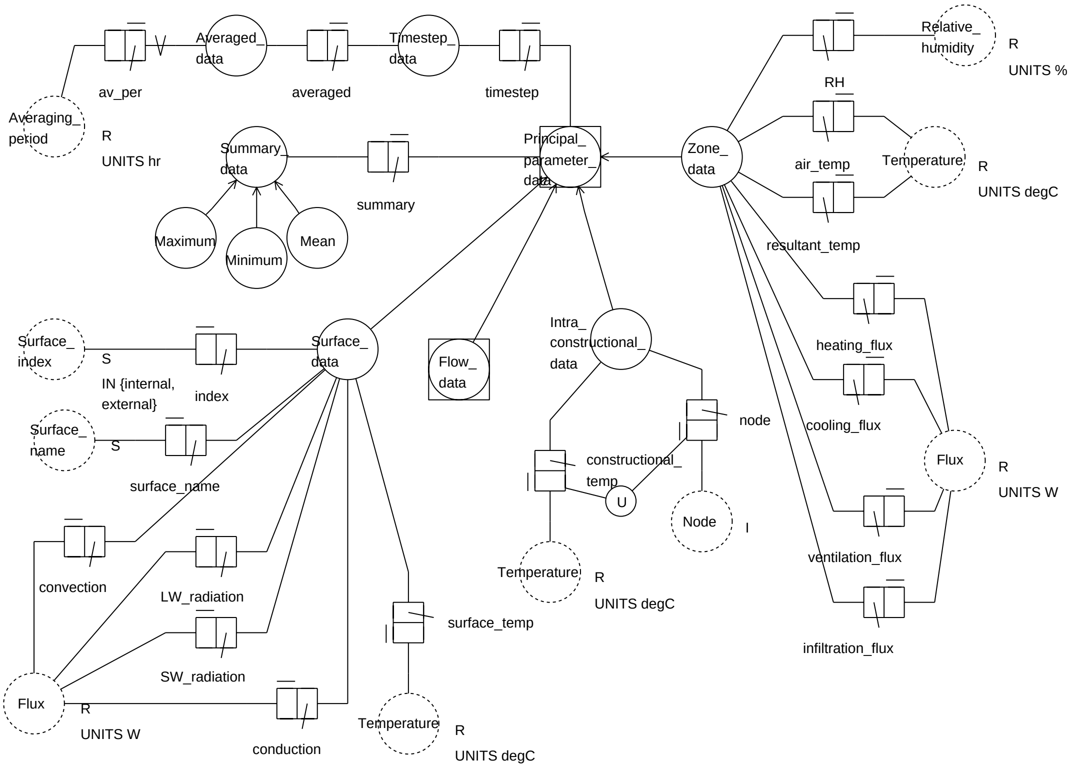

Figure 40 Principal_parameter_data diagram (referenced by: performance_assessment).

9.3 Derived_performance_data

Derived_performance_data (Figure 41) is design question information from the user’s perspective. It includes the subtypes: Energy_balance (all flux paths at either Zone_energy_balance or Surface_energy_balance), Plant_size (derived capacity), Condensation_risk (a simple Yes/No response or a list of surfaces on which condensation occurs), Energy_consumption (per unit of time or integrated over time) and Comfort (one of several derived indices).

Associated data: Flux_name (convective, radiative, etc.).

9.4 Comfort

Comfort ESP-r supports comfort analysis (Figure 42) as either a simple overheating or underheating analysis, or a detailed analysis of the comfort conditions at each timestep. Time, Comfort_assessment, Predicted Mean Vote (PMV), Percentage People Dissatisfied (PPD), Temperature (mean radiant and standard effective temperatures) are reported at each timestep.

Comfort_assessment: This is a text string describing comfort conditions ("comfortable, pleasant", "slightly cool, acceptable", etc).

Associated data: Activity_level, Air_speed, Clothing_value are assumed constant for the analysis period.

Heating_risk assesses whether the analysed zone(s) overheat or underheat. A list of overheating zones is given, together with the criterion for assessment (frequency or extremes of resultant temperature or air temperature).

9.5 Flow_data

Flow_data (Figure 43) contains results from the solution to the mass flow network at each timestep. It is composed of Pressure_data (at each node), and Flow_rate_data (along each connection in the network).

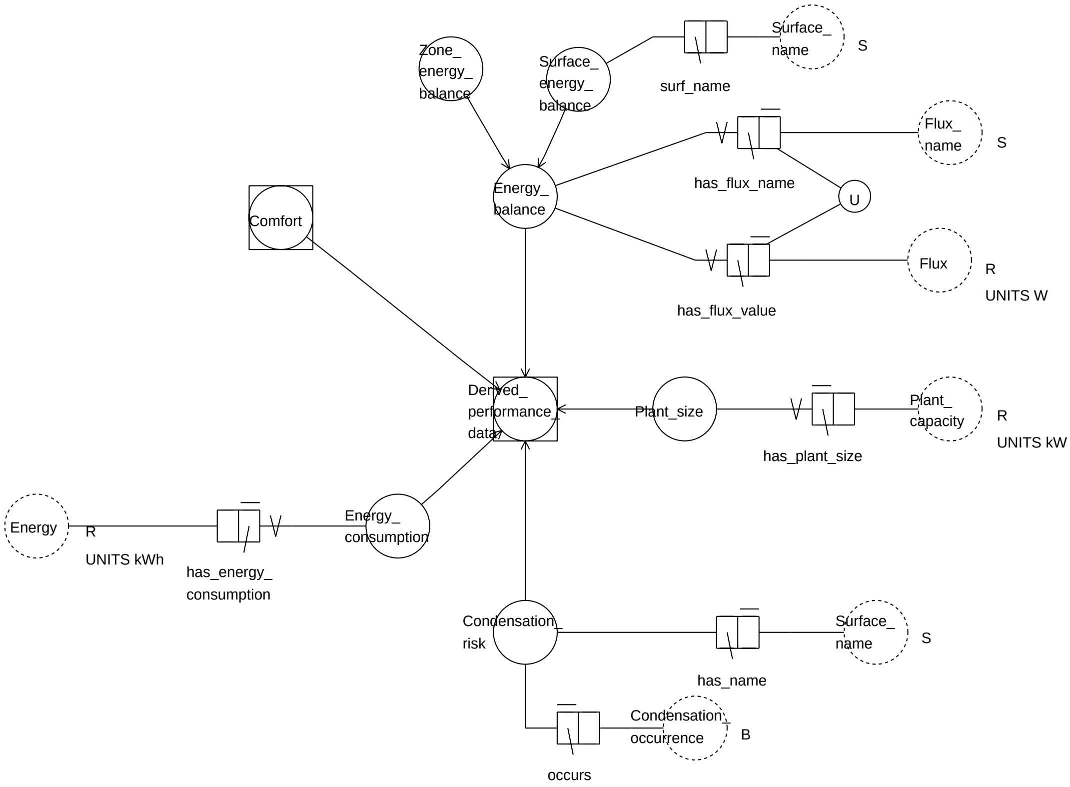

Figure 41 Derived_performance_data diagram (referenced by: performance assessments).

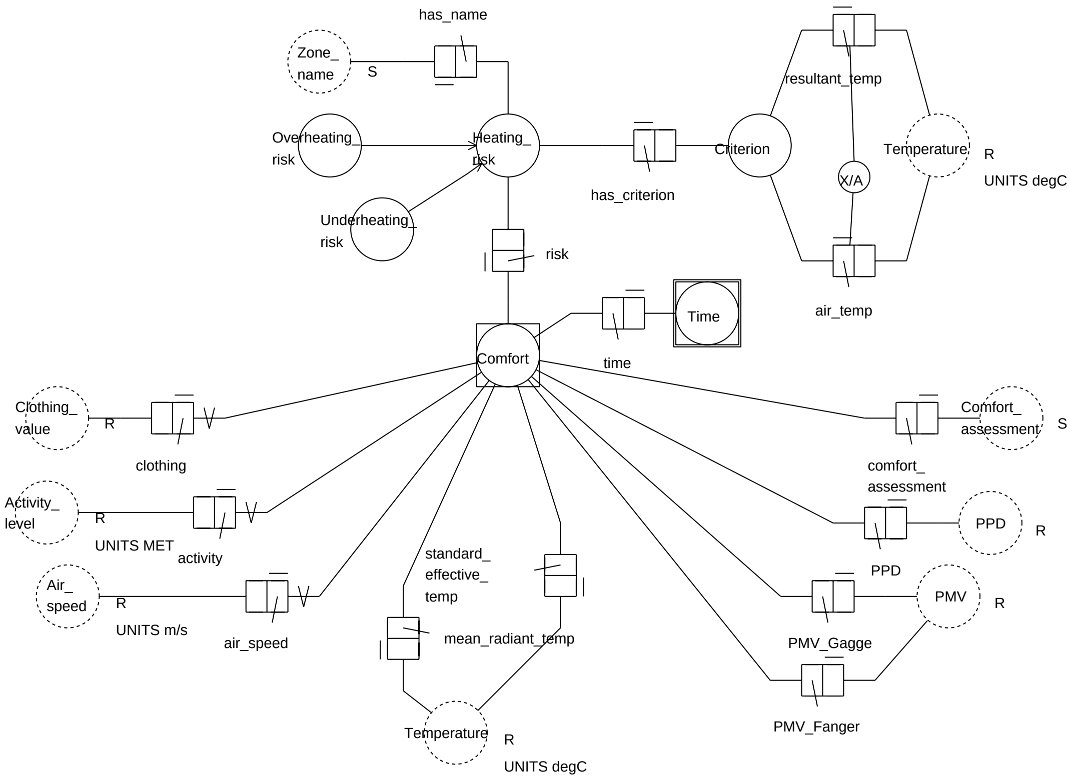

Figure 42 Comfort diagram (referenced by: derived_performance_data).

9.6 Parameter_distribution_data

Parameter_distribution_data (Figure 44) describes the distribution of data in a zone in terms of: Radiation_distribution (Short_wave_radiation and Long_wave_radiation), Temperature_distribution, Pressure_distribution (pressure distribution in the zone of interest and any nodes connected to it in the network) and Flow_distribution (flow through all connections to the zone of interest). It has a time associated with it: the distribution is reported at each timestep in the analysis period.

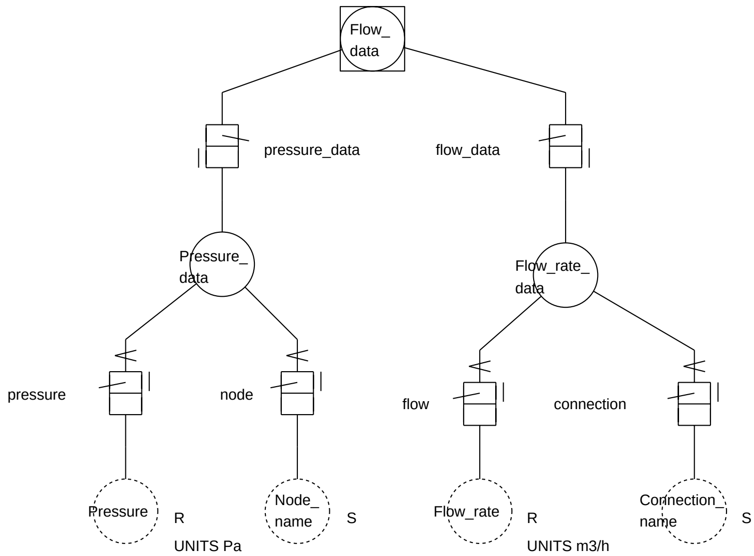

Figure 43 Flow_data diagram (referenced by: principal_parameter).

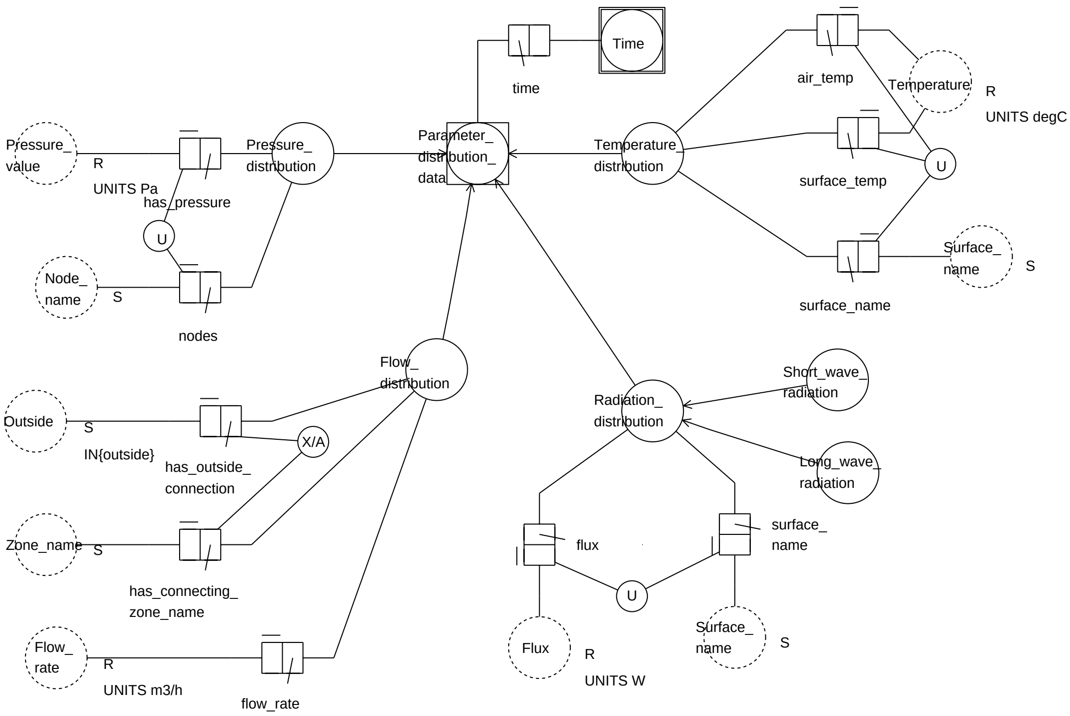

Figure 44 Parameter_distribution diagram (referenced by: performance_assessment).

9.7 Building_property

Building_property (Figure 45) are internally calculated properties of the building which may be of use in other design tools. Examples are: Sun_position (elevation and azimuth for any time or date), zone Volume (derived), Surface_area (derived), Viewfactor_data (for each surface pair derived by area-weighting or ray tracking calculations) and Shading_data (temporal shading coefficients for outside surfaces). Each Building_property relates to zone-level information except sun position, which is dependent only on the site location.

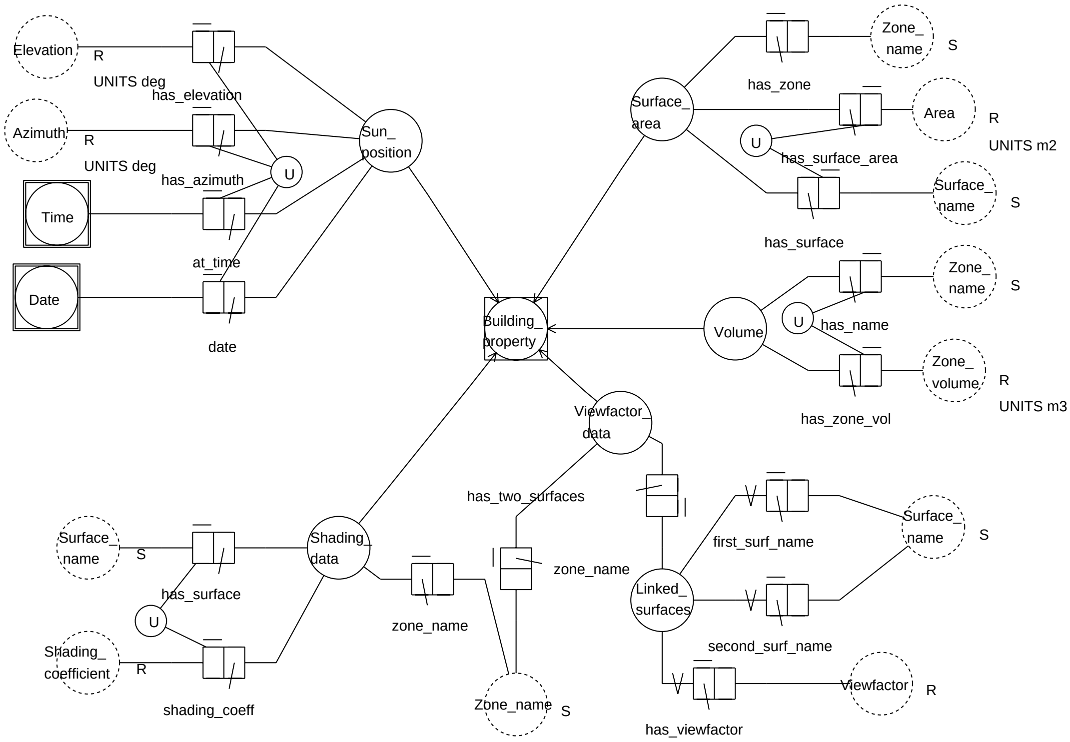

Figure 45 Building_property diagram (referenced by: ESP-r).

10 Flow

10.1 Flow_network(s)

The **Flow_network** (Figure 46) is the highest level entity on the network flow side of the problem description. Networks consist of nodes, components and connections. Both air and water flow networks are possible (with an easy extension to other fluids if necessary).

A **Flow_node** represents a bookkeeping point in a network at which pressures and temperatures are known or are calculated.

Flow_connection specifies the links between nodes, with one component linking each specified pair of nodes. Relative heights from the connection to the nodes are required.

Flow_component is a components used within the network (.e.g fan, duct, valve).

Associated data: Wind_speed_reduction_factor (to convert from the wind speed in the climate file to a building reference height).

10.2 Flow_node

A **Flow_node** (Figure 47) represents a position in the network at which pressures and temperatures are known or are calculated. It can either be a boundary node or an internal node. Mass balance calculations are undertaken only at internal nodes.

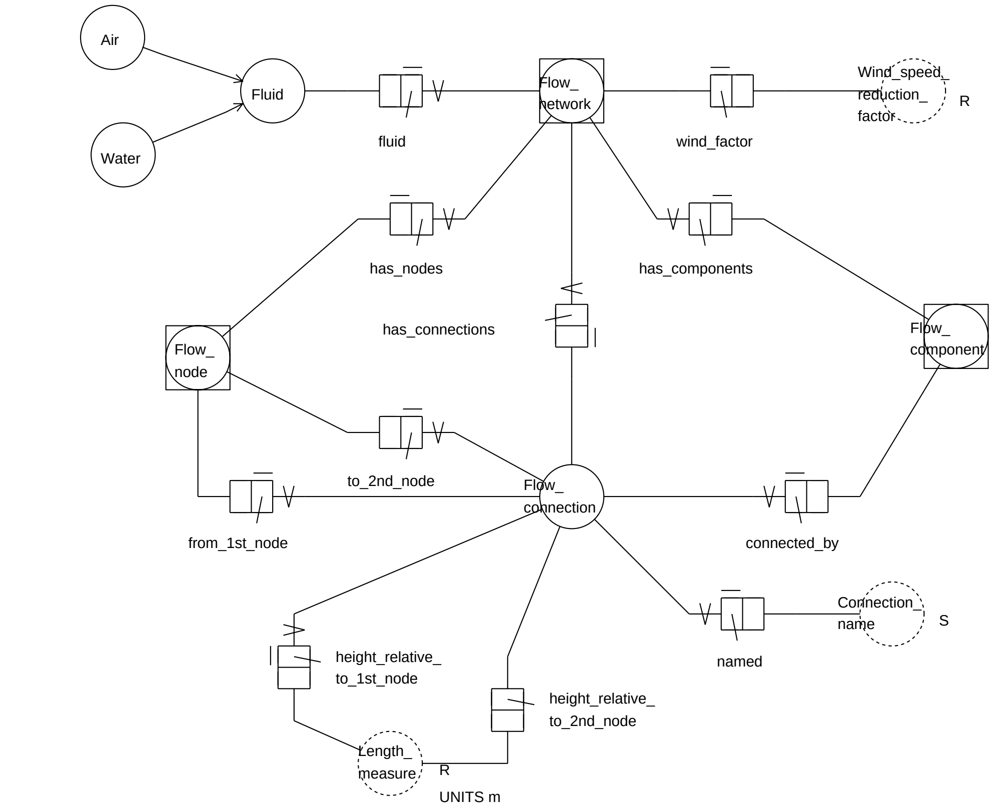

Figure 46 Flow_network diagram (referenced by: ESP_r_problem).

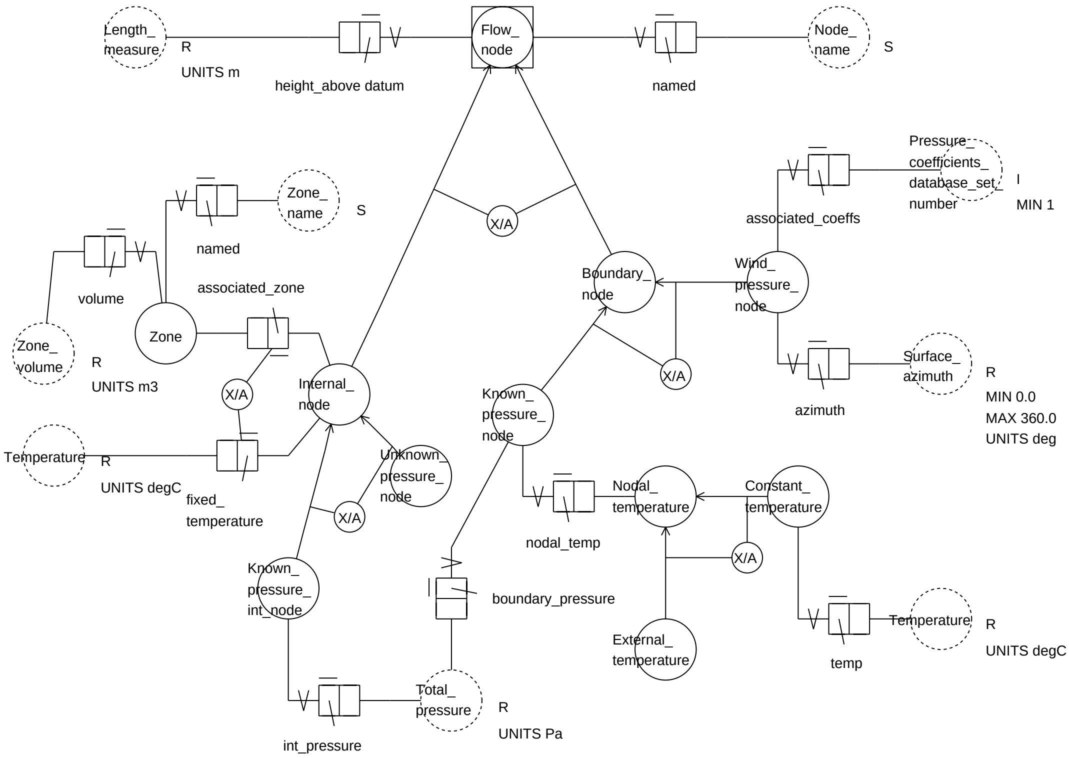

Figure 47 Flow_node diagram (referenced by: flow_network).

A **Known_pressure_node** represents a position in the network at which pressures are known.

An **Internal_node** is usually an Unknown_pressure_node (and is calculated in the simulation) but may also be a Known_pressure_int_node. Its associated temperature can be either fixed, or calculated as part of the building simulation: in the latter case the associated zone is required.

A **Boundary_node** can either be a Wind_pressure_node (only for airflow networks but this constraint is not explicit on the diagram) or a node at which the pressure is known. If it is a wind pressure node, its temperature is automatically taken from the climate database.

Associated data: Pressure_coefficients_database_set_number (reference to the appropriate set in the pressure coefficients database), Surface_azimuth (degrees clockwise from north) and Zone_volume (for calculation of air change rates).

10.3 Flow_component

Flow_component(s) (Figure 48) are components used within the network. Examples are flow resistance components such as fans and ducts. They can be referenced in one or more places in the network. Some of the components are suitable for a fluid type of air only (not shown in the diagrams). Each component has a Component_name.

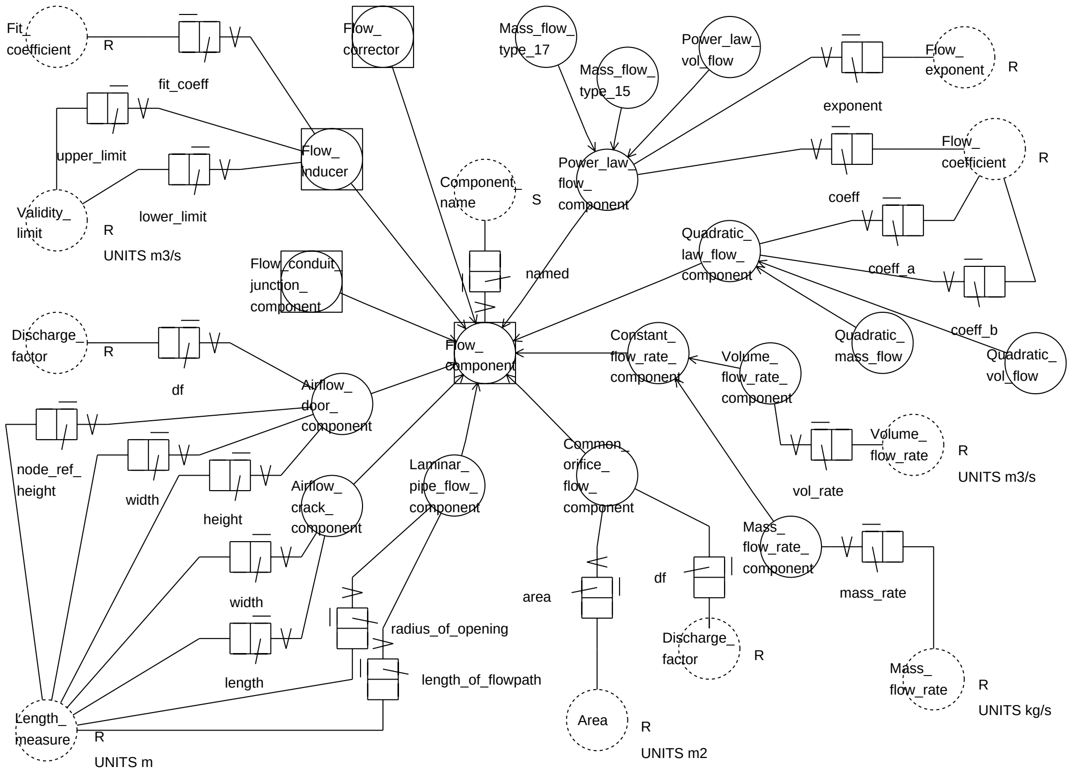

Figure 48 Flow_component diagram (referenced by: flow_network).

Power_law_flow_component has three subtypes (Power_law_vol_flow, Mass_flow_type_15, Mass_flow_type_17) each with a different dimension for the flow coefficient. A Flow_coefficient and Flow_exponent must be specified.

Quadratic_law_flow_component has two subtypes (Quadratic_vol_flow, Quadratic_mass_flow) with different dimensions for the flow coefficients.

Mass_flow_rate_component is an ideal representation of a fan or pump requiring a mass flow rate.

Volume_flow_rate_component is an ideal representation of a fan or pump requiring a volume flow rate.

Common_orifice_flow_component represents turbulent flow through relatively large openings.

Associated data: Discharge_factor (assumed to be 0.65).

Laminar_pipe_flow_component represents laminar flow along relatively long flow paths. Both the radius of the opening and length of flow-path are required.

Airflow_crack_component represents a crack. Both length and width are required.

Airflow_door_component is a Flow_component which supports bidirectional flow through a vertical opening. Both height and width of a door are required, together with the reference height of the neutral flow point and a discharge coefficient.

Flow_inducer represents a pump or fan. It requires a Fit_coefficient (coefficients a0 to a3 must be specified) as well as a Validity_limit within which the polynomial is applicable.

10.4 Flow_conduit_component

Flow_conduit_component(s) (Figure 49) are available in five variants: a flow conduit with no junction and converging and diverging three and four leg junctions. All have the same basic attributes. The more complex junctions have additional coefficients.

Associated data: Length_measure (absolute wall roughness, conduit length, cross-sectional area and hydraulic diameter) and Local_loss_factor (sum of the local loss factors).

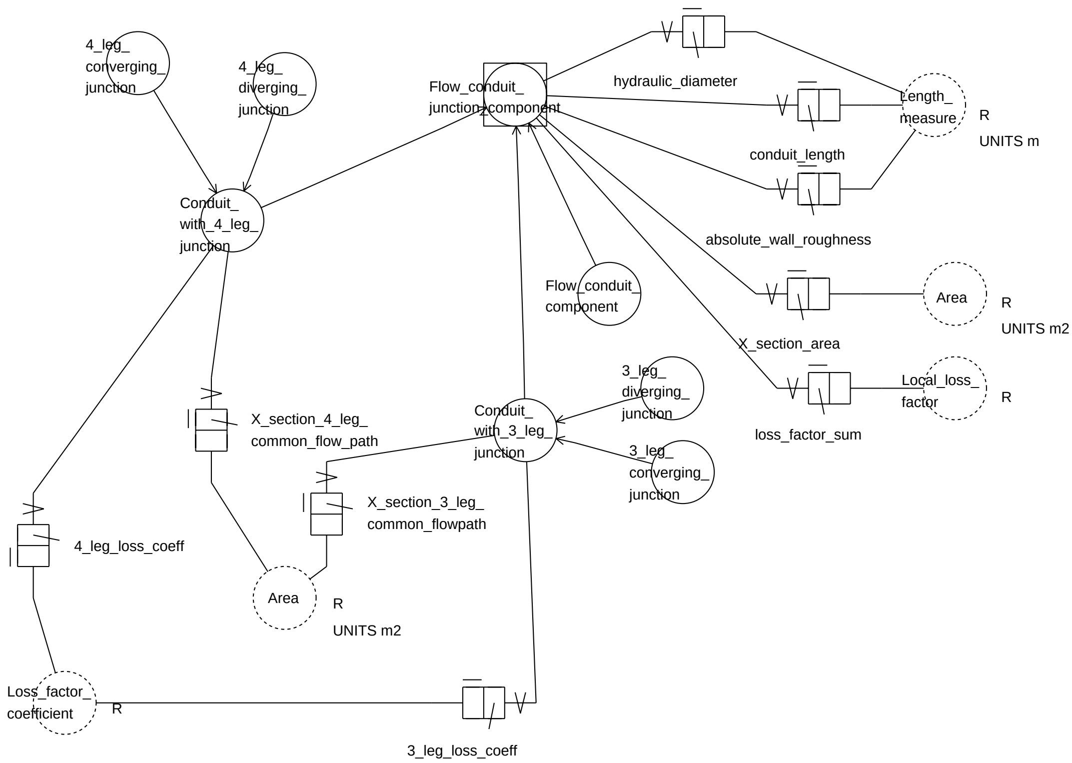

Figure 49 Flow_conduit_component diagram (referenced by: flow_component).

Conduit_with_3_leg_junction has two subtypes: 3_leg_converging_junction and 3_leg_diverging_junction.

Associated data: Area (cross-section of the common flow path of the 3_leg junction, Loss_factor_coefficient, and a Fit_coefficient (coefficients a0 to a5).

Conduit_with_4_leg_junction has two subtypes: 4_leg_converging_junction and 4_leg_diverging_junction.

Associated data: Area, Loss_factor_coefficient and a Fit_coefficient (coefficients a0 to a9).

10.5 Flow_corrector

A **Flow_corrector** (Figure 50) represents valves and dampers. There are two subtypes: a General_flow_corrector (variable valve or damper used in flow control loops) and a Flow_corrector_with_polynomial_flow_resistance (response of the flow corrector is described in terms of local loss factors, from a third order polynomial fit).

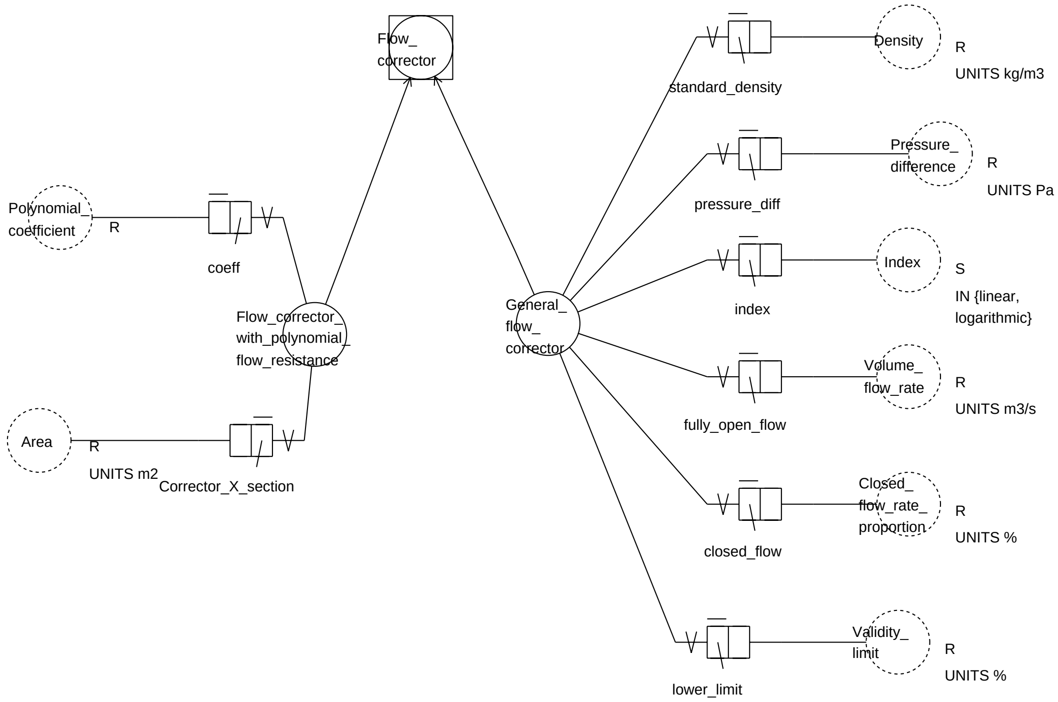

Figure 50 Flow_corrector diagram (referenced by: flow_component).

Associated data: Density (of fluid), Pressure_difference (standard), an Index of flow characteristic (1=linear, 2=logarithmic), Volume_flow_rate (when fully open), Closed_flow_rate_proportion (theoretical flow when closed), Validity_limit (lower limit for flow), a Fit_coefficient (4 coefficients a0 to a3) and Area (X-section of the corrector).

11 Flow Control

This section gives details on the flow control decomposition. It is similar in structure to building control.

11.1 Flow_control

Flow_control (Figure 51) is the highest level diagram for flow control. It contains references to sensors, actuators and to the flow control types and laws (which can be scheduled).

Each **Flow_control_function** has information on a Flow_sensor_point (the location of the sensor) and a Flow_actuation_control_point (location of the actuation control point).

Control_specification is defined so that one or more Flow_control_law (control algorithms representing the logic of some, real or imaginary, controller) can be scheduled.

Flow_control_type determines the properties that are sensed and actuated. These remain constant (only Flow_control_law can be scheduled.

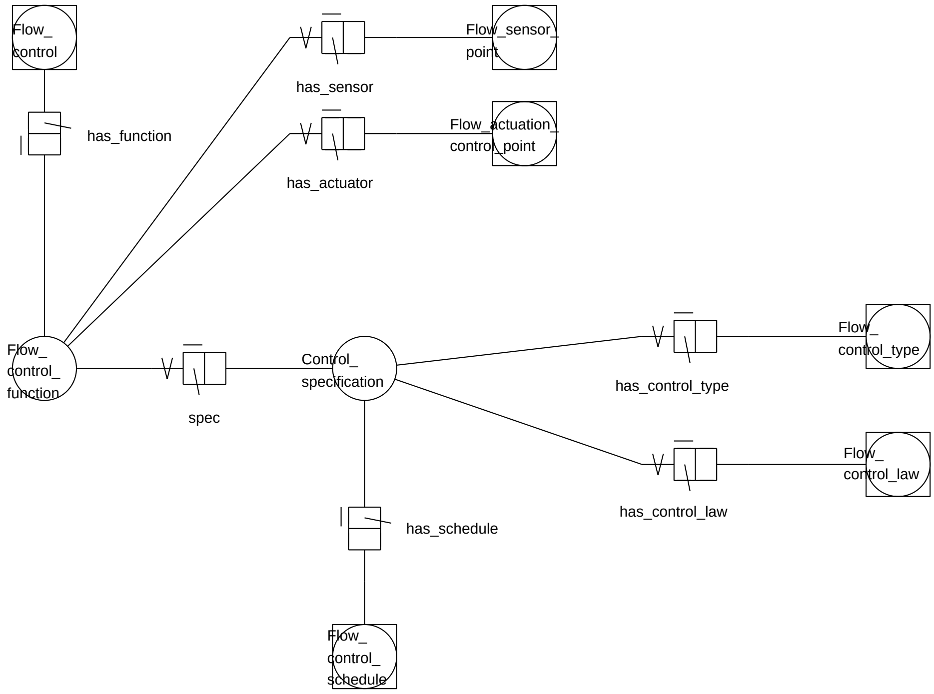

Figure 51 Flow Control diagram (referenced by: ESP_r_problem, schedule).

11.2 Flow_sensor

Flow_sensor(s) (Figure 52) can be placed at a Mass_flow_node, or a Mass_flow_connection. It is also possible to sense building-side sensor points.

11.3 Flow_actuation_control_point

Flow_actuation_control_point(s) (Figure 53) can either be at a Flow_connection_control_point or on a Flow_component_control_point. In the latter case, the user must indicate the associated connections.

Associated data: Component_name and Connection_name (set of connections for which the component is controlled). Where different connections are being controlled with the same component, the sensed node is required for each connection.

11.4 Flow_control_type

Flow_control_type (Figure 54) comprises the set of control types associated with each Sensed_property and Actuated_property in a flow network.

Sensed_property includes a number of subtypes which are mutually exclusive, (although this has not been depicted on the diagram). The subtypes are: External_relative_humidity, Direct_normal_solar_rad, Diffuse_horiz_solar_rad, Wind_speed, Wind_direction, Absolute_mass_flow_rate, Pressure_difference, Absolute_pressure_difference, Pressure, Absolute_temperature_difference, Temperature_difference, Relative_humidity, 2nd_phase_mass_flow_rate, 1st_phase_mass_flow_rate, Enthalpy and Temperature.

The **Actuated_property** for network flow is the mass flow rate.

11.5 Flow_control_law

Flow_control_law (Figure 55) has three subtypes: On_off_controller (based on set-point temperature and direct/ inverse action), Linear_controller_with_hysteresis (generally used with the flow corrector flow components) and a Range_based_controller (not shown on the diagram, but responds as scheduled air flow with minimum, normal, default and extreme ranges).

Associated data: Upper and lower limits for the signal, Relative_position (of the controlled variable at the upper and lower signal limits) and Signal_difference (signal difference required to overcome hysteresis).

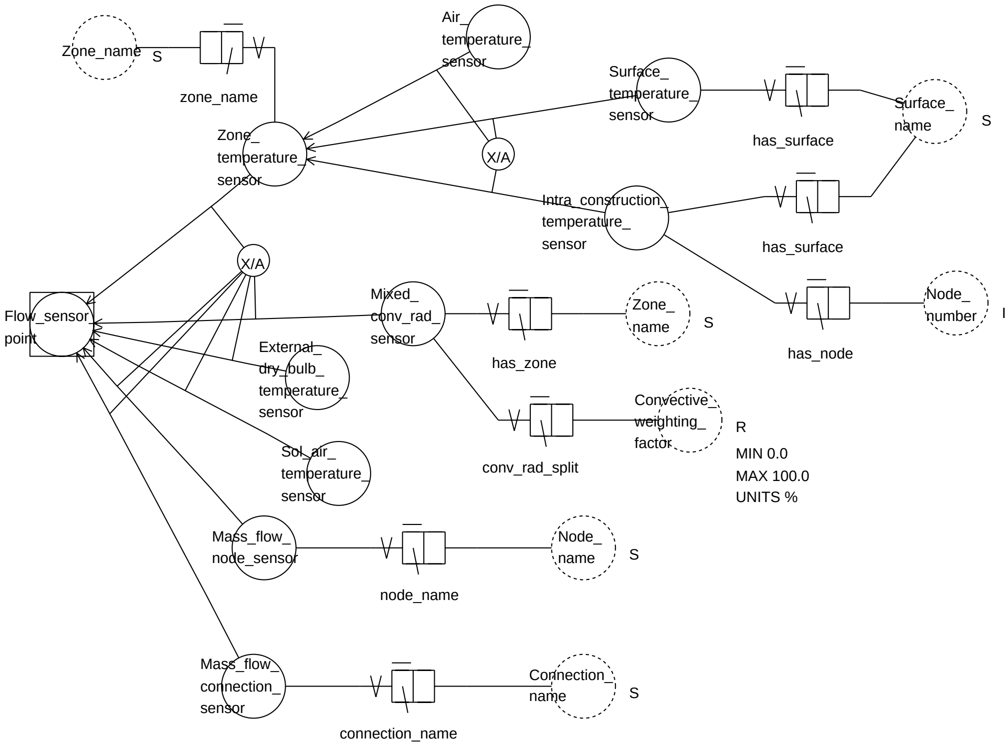

Figure 52 Flow_sensor diagram (referenced by: flow_control).

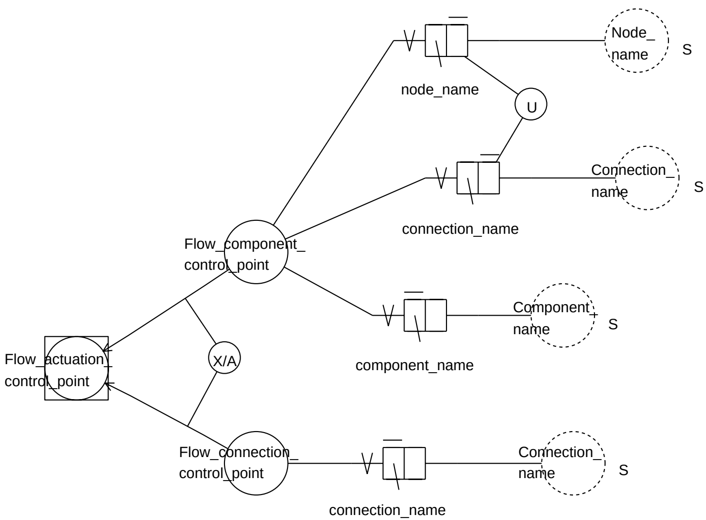

Figure 53 Flow_actuation diagram (referenced by: flow_control).

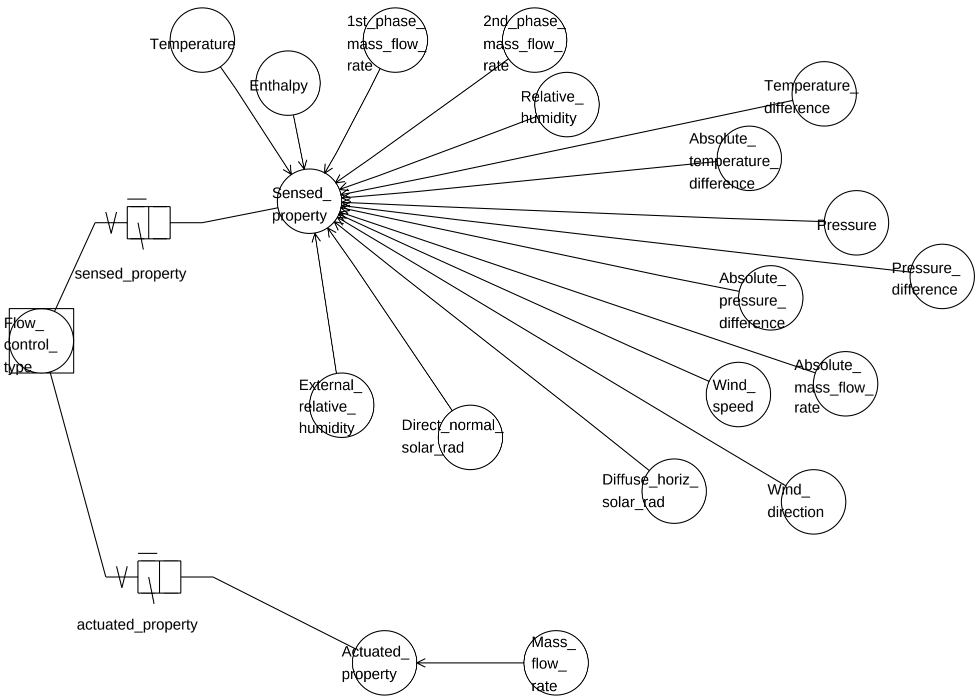

Figure 54 Flow_control_type diagram (referenced by: flow_control).

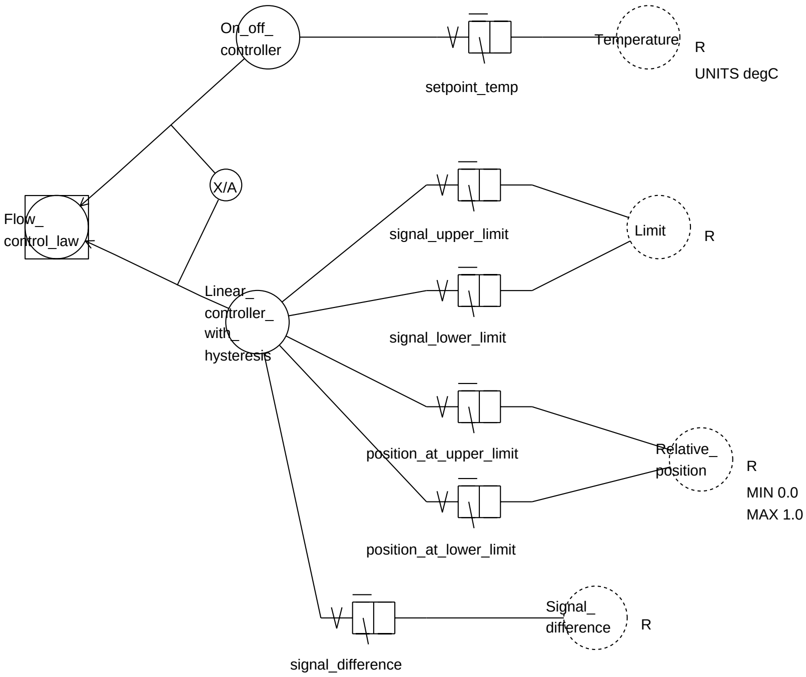

Figure 55 Flow Control_law diagram (referenced by: flow_control).

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