Towards an ontology-based system to foster Older Adults' Mental health via Indoor Comfort management

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Abstract

The growing aging population raises critical challenges for mental health and independent living among older adults. Indoor comfort metrics — encompassing lighting, temperature, air quality, and ventilation — have been recognized as a key determinant of psychological well-being. Despite the evolution of Ambient Assisted Living (AAL) technologies, few systems directly address how indoor comfort affects mental health in older adults, a task requiring a multidisciplinary approach. This paper introduces OAIC (Older Adults Indoor Comfort), an ontology-based framework designed to bridge this gap by enabling intelligent, personalized indoor comfort management tailored to the mental health needs of the elderly. OAIC integrates standard ontologies such as SOSA, ICF, and ICD and models both general and tailored comfort settings based on expert knowledge and clinical metrics like the Geriatric Depression Scale. Through semantic rules, the system enables detection of deviations from comfort thresholds and triggers appropriate environmental adjustments via actuators. Two use cases illustrate the system's functionality in supporting individuals with depression and sleep disorders. The ontology was developed following the AgiSCOnt methodology, ensuring iterative collaboration with domain experts. Although in a prototypical phase, OAIC demonstrates strong potential to enhance mental health in aging populations by supporting non-pharmacological interventions through intelligent environmental adaptation. Future validation and stakeholder engagement are essential to assess its efficacy and broaden its adoption.

Keywords

Ontology-Based Systems, Ambient Assisted Living, Indoor Environmental Quality, Older Adults' Mental Health, Indoor Comfort Metrics

1. Introduction

The progressive aging of the population is becoming a relevant issue for many countries worldwide. In 2023, the World Health Organization (WHO) observed an increase in worldwide life expectancy up to 73 years old [1] – which happened in the past 75 years as a consequence of general wellbeing. Life expectancy is longer in Western countries, although the aging problem affects all countries [2]. In Europe, most countries are facing an increase in the percentage of older adults (i.e., people aged 65 or more) and, at the same time, a decrease in birth rates. This situation – also known as *greying of Europe* phenomenon – is expected to exacerbate by 2050, when the number of older adults in Europe will touch 45% of the total EU-27 population [3].

Aging implies older adults often suffer from chronic conditions, including sensory loss, cognitive decline, cardiovascular conditions, and impaired mobility, which can ultimately culminate in disability [4, 5]. For older adults aged 85 or older, physical and cognitive impairments are expected to be systematic [6]. Alongside physical impairments, mental health issues are common in adults over 65. Depression, anxiety, loneliness, social isolation, and dementia are among the conditions that affect more than 20% of this population, with symptoms often difficult to diagnose or mistaken as the results of aging [7]. Furthermore, in some countries (e.g., some European countries, China, etc.), aging can result in an increase in the national healthcare expenditure, which has to cover long-term care [8].

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In the past decade the WHO promoted Active Aging, a multidimensional and holistic approach that includes physical, mental, and social well-being, as well as ongoing engagement in social, economic, cultural, and civic activities. Active Aging is expected to make older adults healthier, socially-connected, and make them live independently for longer periods of time [9, 10]. From a technological perspective, Ambient Assisted Living (AAL) [11] emerged in the early 2000s as a technological paradigm to support older adults' independent living – particularly in Activities of Daily Living. AAL received a significant push during the last ten years by the further development of other technological paradigms (i.e., Context Awareness, Internet of Things, Ambient Intelligence), which contributed to the development of prototypical solutions in the areas of smart homes and assistive devices.

Among the features of interest, AAL solutions also touch on indoor environmental quality (IEQ) and its conditions. IEQ plays a significant role in human health, with key factors including thermal comfort, indoor air quality and ventilation, visual and acoustic comfort, hygiene, and safety. In particular, researchers have focused their attention on the effects air pollutants and air quality have on health [12], which can also include mental issues. The effects of indoor temperature and lighting have also been intensively investigated [13, 14]. The problems generated from indoor environmental conditions are also a concern for older adults, particularly for those characterized by chronic conditions. In particular, air quality and pollution have been found to significantly exacerbate respiratory conditions and to impact mental health as well, contributing to increased depressive and anxious symptoms [15, 16]. Several studies underline the correlations between noise levels, indoor temperature, lighting levels, and the emotional well-being of older adults. These environmental factors can play a pivotal role in exacerbating mental illnesses, decreasing sleep efficiency, and accelerating cognitive decline (as summarized in Peralta et al. [17]). Indoor comfort-related issues are also a major concern for older adults in residential settings and nursing homes [18].

These considerations highlight the primary role AAL solutions can cover in supporting older adults living autonomously and in a healthy way by leveraging advanced technologies for indoor environmental monitoring and control. Specifically, the continuous assessment of key comfort parameters enables AAL systems to maintain optimal living conditions tailored to the needs of elderly individuals. By ensuring a stable and healthy indoor environment, these systems help mitigate the impact of environmental factors on mental health, thus contributing to the prevention of cognitive decline and mental health deterioration.

However, AAL solutions are mostly focused on physical impairments and mild cognitive disabilities (ranging from mild memory issues to early stages of dementia), with interventions devoted to identifying potential health risks, medication management, daily activities reminders, and behavioral support [19, 20, 21]. Indoor comfort metrics and their management in AAL solutions are often treated as a secondary aspect or assumed to be inherently adequate, with primary focus placed on safety, mobility, and medical monitoring. As a consequence, there is a notable lack of Ambient Assisted Living (AAL) solutions specifically designed to manage indoor comfort as a means of mitigating mental health risks among older adults. Moreover, addressing this gap requires a multidisciplinary approach that involves both clinical and non-clinical personnel in the monitoring and adaptation of indoor environments to support older adults' mental health.

This work presents a prototypical ontology-based system to address the identified research gap. Specifically, this paper introduces an ontological framework (Older Adults Indoor Comfort - OAIC) and its engineering process, focusing on the modelling choices aimed at supporting the mental well-being of older adults. The remainder of this paper is organized as follows: Section 2 highlights some of the most relevant works in this field, while Section 3 provides the theoretical background on older adults' mental health issues and presents the results of a literature survey on the topic of indoor environmental conditions and their effects on the elderly. Section 4 delves into the OAIC ontology engineering process, illustrating the resources involved in the process and the resulting model. Section 5 presents two use cases to describe the expected functioning of indoor comfort management performed with the ontology. Section 6 discusses some limitations of the proposed approach and outlines the future research directions, including proposals for validating OAIC and its inferences. Finally, the Conclusions summarize the main outcomes of this paper.

2. Related work

The use of ontologies for modelling indoor comfort metrics and to act as the backbone of AAL solutions is no novelty. In the past fifteen years, many articles have tackled the issue of modelling occupants, their needs, impairments, devices and actuators, and human activity within AAL frameworks. Indoor comfort metrics, however, were not often the main focus of ontology engineering, nor were older adults' mental health needs. In most of the ontology-based AAL solutions, the main comfort metrics impacting human health – i.e., indoor air quality, temperature, humidity, lighting, and noise – were implicitly modelled as a collection of data (coming from sensors) [22]. Sometimes, occupants' preferences in a smart environment include comfort metrics: in the AATUM ontology, a Preference class includes the possibility to specify a user's preferred temperature value for a room or a lighting setting when the user performs specific activities (such as watching TV with lights off)[23]. In other ontologies, such as OntoDomus [24], comfort is nuanced as one of the contextual elements of a smart environment, and its management seems to be relegated to a matter of measurements performed by sensors.

After 2020, when research on the role played by indoor comfort on human health was being explored more extensively, even AAL solutions started to pay more attention to comfort modelling and to carve out a more relevant role for it. In [25] and [26], temperature, lighting, and air quality measurements performed by sensors are used to trigger some actuations – aimed at avoiding the exacerbation of occupant's physical conditions, such as respiratory, visual, or cardiovascular ones. In these works, occupants' impairments are modelled leveraging international health standards, i.e., WHO's International Classification of Functioning, Disability and Health (ICF)[27] or International Classification of Diseases (ICD)[28], and a set of rules assigns to each condition a suitable comfort metric setting. Unlike these works, ComfOnt[29] – a domain ontology developed to support occupants with special needs in managing domestic appliances' energy consumption while maintaining their preferred levels of indoor comfort – builds on the concept of occupant's comfort settings: the current environmental conditions – assessed via a network of sensors – are compared against the preferred temperature, lighting and air quality values modelled within the ontology. A set of rules triggers appropriate actions when any of the parameters deviate from the specified comfort range.

The integration of comfort metrics and energy saving in ontology-based smart solutions is also represented in more recent efforts. For example, IAQ focuses on modelling indoor air quality (specifically, temperature, humidity, PM2.5, and PM10) to improve occupants' health, comfort, and energy consumption. Also in this case, ICF-based health profiles describing physical conditions (including chronic ones) are linked to comfort settings via rules. Sustainable and efficient energy consumption with indoor comfort is also the aim of the AAL solution described in [30], an ontology-based digital twin that models, among other concepts, occupants' preferences in terms of indoor comfort (with specific reference to indoor temperature and humidity). Also in [31], the ontology provides a digital twin for the integration of heterogeneous data (sensor data, occupants' characteristics, weather, etc.) and to inform actuators (e.g., HVAC, lighting, etc.) so that they can respond dynamically to occupants' preferences. However, it is worth observing that while all the solutions are devoted to supporting older adults and meeting their specific needs, the cognitive and mental health aspects of the elderly are often neglected. In some works, it is hinted that the proposed solutions may support occupants' cognitive aspects, but no actual modelling of the relationships occurring between indoor comfort metrics and mental health issues is presented. On the contrary, the solution presented in Section 4 aims at making these relationships explicit and exploiting them for actuating indoor comfort modifications capable of fostering occupants' mental health.

3. Indoor Environmental Conditions and Mental Health in Older Adults

Mental health challenges in older adults, including depression, anxiety, sleep disturbances, and cognitive decline, are increasingly recognized as critical public health issues [32]. According to WHO's data, 14%

of older adults live with a mental disorder, and around 27% of suicides are among people aged 60 or more. Age-related biological changes such as altered circadian regulation, reduced thermoregulation, sensory decline, and increased sedentary behavior render this population especially sensitive to environmental factors. These vulnerabilities are compounded by social isolation and reduced mobility, leading to increased time spent indoors. Consequently, IEQ - encompassing lighting, temperature, and ventilation - emerges as a crucial determinant of mental health in older adults. In the following, the main indoor comfort metrics impacting older adults' mental health are discussed. Recent evidences from literature reviews were gathered and summarized to provide an overall picture of the role played by IEQ in exacerbating or reducing mental-related conditions, focusing on those metrics that constitute the main focus of the proposed OAIC ontology-based system.

Sleep and circadian rhythm: In the elderly population, circadian rhythm disruption is a core mechanism linking environmental stimuli to psychological outcomes. Light and temperature are key "zeitgebers" (time cues) that help synchronize circadian rhythms [33]. Poor lighting, thermal discomfort, and insufficient ventilation may contribute to physiological stress, hormonal imbalance (e.g., melatonin suppression, cortisol elevation), and neuroinflammation: factors associated with mood disorders and sleep problems.

Lighting exposure: Light exposure plays a pivotal role in regulating circadian rhythms, mood, and cognitive function in older adults. Circadian lighting systems that simulate natural daylight cycles, with gradual shifts in intensity and colour temperature, have demonstrated benefits in reducing depressive symptoms and agitation while enhancing sleep quality [34]. High-intensity daytime light exposure has been associated with improvements in cognition and decreases in depressive symptomatology over both short and long-term periods [35]. These improvements are linked to better circadian rhythm stabilization and sleep efficiency, both commonly disrupted in depressive disorders. Satisfaction with indoor lighting correlates positively with emotional well-being, whereas inadequate lighting is associated with increased loneliness, negative affect, and sleep disturbances [36]. Although some studies report mixed results, the preponderance of evidence supports appropriate lighting interventions as an effective non-pharmacological approach to enhancing mental health, particularly for those with limited mobility or cognitive impairment. A review of current literature reveals consistent associations between IEQ parameters and mental health outcomes in the elderly: daylight and circadian-aligned artificial lighting are shown to mitigate depression and improve sleep quality. Controlled trials demonstrate that daytime exposure to bright light (2,500 lux) significantly reduces depressive symptoms and increases sleep efficiency in older adults, including those with dementia [37, 38]. Conversely, nighttime exposure to indoor lighting above 5 lux has been linked to a higher risk of depression, likely through circadian disruption and melatonin suppression [39].

Temperature: Depression, cognitive impairment, and dementia are significantly influenced by environmental conditions, particularly temperature regulation. Elevated ambient temperatures and greater temperature variability have been strongly associated with negative psychological and cognitive outcomes in older adults. Meta-analytic evidence [40] highlights that inadequate indoor temperature control can exacerbate these mental health conditions, underlining the importance of maintaining a stable and comfortable indoor climate for emotional well-being in aging populations. Periods of extreme heat often coincide with spikes in hospital admissions and mortality among older adults, especially those with pre-existing mental health conditions or who are socially isolated. While older adults generally prefer warmer indoor temperatures than younger individuals, surpassing comfort thresholds can lead to reduced life satisfaction and heightened psychological distress [17]. Conversely, prolonged exposure to low indoor temperatures is frequently associated with depressive symptoms, disrupted sleep, and diminished quality of life [41]. Cold environments provoke physiological stress responses, potentially triggering or worsening depression, particularly in those with impaired mobility or thermoregulatory capacity. Additionally, short-term temperature fluctuations, such as diurnal temperature range, have been linked to increased hospital admissions and mortality from mental illness [42]. Depression is especially sensitive to such variability, with symptoms like anxiety and hopelessness often emerging during sudden temperature changes. Challenges remain in precisely attributing effects due to the reliance on outdoor temperature data without detailed indoor exposure assessments. Furthermore, individuals with dementia exhibit altered thermal perception and responses, necessitating personalized thermal management strategies to reduce agitation and improve sleep quality [43]. Thermal comfort plays a vital role in both cognitive performance and emotional regulation. Studies identify a thermoneutral zone between 20–24°C (68–75°F) as optimal for older adults. Exposure to temperatures outside this range is associated with impaired cognitive performance, poor sleep quality, and increased psychological stress [44, 45]. Nighttime heat in poorly ventilated or uncooled environments, common in institutional settings, exacerbates sleep fragmentation.

Air quality: Air quality is another essential determinant of mental health and cognitive function. Exposure to fine particulate matter (PM2.5), PM10, nitrogen dioxide (NO), and ozone (O) has been consistently linked to increased risks of depression, anxiety, cognitive decline, and neurodegenerative diseases such as dementia [46, 47, 48]. For example, a 5 g/m^3 rise in PM2.5 has been associated with a 0.62% increase in depressive symptoms [46]. These effects are mediated through systemic inflammation, neuroinflammation, and disruptions in sleep and circadian regulation—key processes implicated in depression. Within residential and care settings, indoor pollutants such as volatile organic compounds (VOCs), carbon dioxide (CO), environmental tobacco smoke, mould, and emissions from fuel combustion have been linked to inflammation, impaired brain connectivity, and elevated anxiety and depression [18]. Frequent exposure exacerbates symptoms of low mood, fatigue, and cognitive slowing. Biological pathways, including oxidative stress, neuroinflammation, and dysregulated cortisol secretion, underpin these associations [48]. Moreover, sleep disturbances and brain structural changes serve as intermediate mechanisms linking pollution exposure to depressive symptoms, particularly in at-risk older adults [47]. Comparative studies highlight the protective effect of cleaner air, with lower depression rates and improved emotional well-being observed in less polluted environments [47]. Intervention studies demonstrate that improving indoor air quality through enhanced ventilation, filtration, and cleaner fuel use reduces depressive symptoms and supports overall mental health [18].

4. OAIC Ontology Engineering Process

The development of OAIC took advantage of an existing agile methodology (AgiSCOnt [49]), which relies on a collaborative approach involving domain experts and ontologists in acquiring a conceptual map of the domain(s) of interest. The knowledge elicitation and acquisition phases benefited from the involvement of domain experts, including clinical personnel (2 gerontologists working in a hospital, 2 psychologists, 2 biomedical engineers), architects and designers (3) involved in the reconfiguration of living environments for older adults, and computer scientists (2). These activities were conducted within the framework of the Italian PNRR Research Project Age-It [1]. Following AgiSCOnt's steps (i.e, *Analysis and conceptualization*, *Development and test*, and *Ontology use and updating*), domain experts were involved iteratively in the definition and refinement of a conceptual map. The prototypical OAIC ontology is available online [2].

4.1. Analysis and conceptualization

During this step, the findings from different scientific and gray literature sources (see Section 3) were gathered and discussed with domain experts. The discussion brought to the definition of a conceptual map (sketched in Figure 1 and which does not rely on any formalism to allow experts' maximum freedom), and the definition of some indoor comfort metrics' specifics, as detailed in the following subsection. In particular, the domain experts deemed it essential to point out that there exists a *neutral* comfort setting, which is suitable for all older adults with mental conditions, although some more severe conditions may require a tailored set of comfort specifications. Also, experts highlighted that the selection of comfort settings (particularly, tailored ones) may be the result of a discussion with the older adult's physician and that the older adult alone may not be self-sufficient in setting the comfort of

[1]Project website: https://ageit.eu/wp/s-p-o-k-e-9/
[2]Ontology available at: https://w3id.org/ontocare/oaic

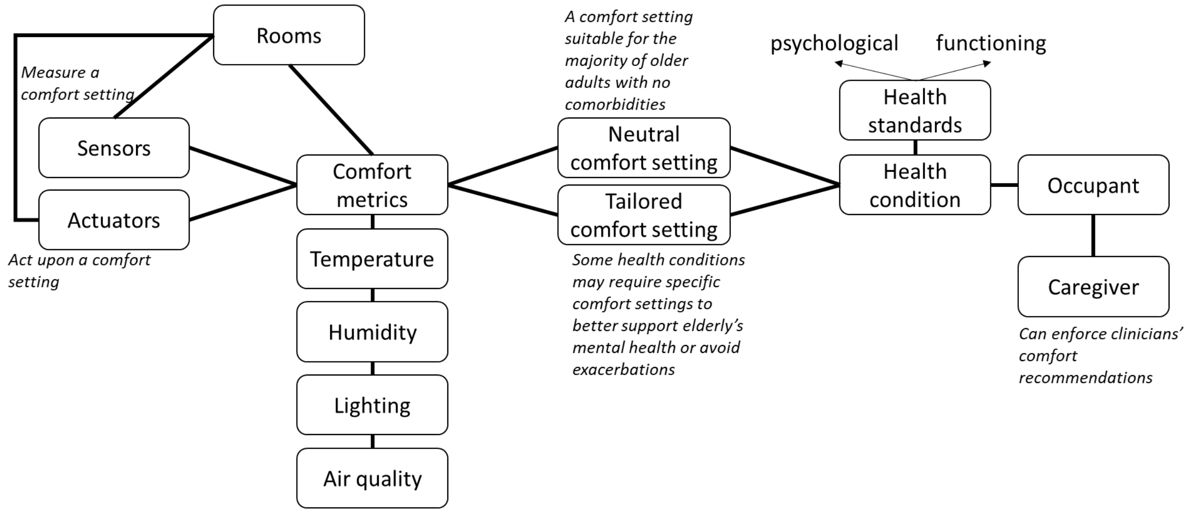

Figure 1: The conceptual map drafted with domain experts.

his/her house, thus requiring the assistance of a caregiver. All domain experts agreed that the scope of the OAIC ontology is to prevent the exacerbation of older adults' mental conditions by modifying the indoor comfort when occupants are sojourning in a room: experts expected the ontology to identify the harmful comfort metrics and to trigger a proper response.

4.2. Development and test

The conceptual map was then converted into an ontology, leveraging OWL 2 DL representation language [50] with the addition of rules written with Semantic Web Rule Language (SWRL) [51]. Considering the domains represented in the conceptual map and the existing ontological models, OAIC was developed based on the following modelling choices:

- The health standards pertaining to psychological and a person's functioning were defined by domain experts; this resulted in the reuse of (subsets of) the ICD and the ICF for the disease and functioning component, and brought to modelling some clinical standards adopted by psychologists to *quantify* common mental conditions, such as anxiety, depression, and sleep disorders. In particular, the need for quantifying some psychological and physical factors emerged as pivotal to understanding the type of adaptations the comfort should undergo.
- The portion of the map depicting sensors, actuators, and their measurements and actuations (performed on some comfort metrics, which are physical magnitudes) relies on the reuse of the Sensor-Observation-Samples-Actuators (SOSA) ontology [52].
- The definition of neutral and tailored comfort settings should be made explicit, so that (if necessary) settings could be changed over time, following occupants' health condition modification.

The reuse of SOSA, ICD, and ICF was performed as "soft reuse" (as defined in [53]), importing those entities that were deemed as relevant for the domains at hand. Also, considering OAIC's specific focus on mental health, only a few ICD classes were modelled, while ICF classes included in OAIC serve the purpose of illustrating the ontology's scalability (i.e., the ontology can possibly encompass also physical *and* mental conditions). The following subsections delve into OAIC's structure.

4.2.1. Health condition

A `oaic:HealthCondition` is linked to its `oaic:Occupant` via the `oiac:hasHealthCondition` object property and is described by relying on an existing ontology design pattern [54] (Figure 2).

This pattern allows linking `oaic:HCDescriptor` individuals to a health condition; each descriptor is characterized by either the ICD code describing the occupant's mental disorder or the ICF codes

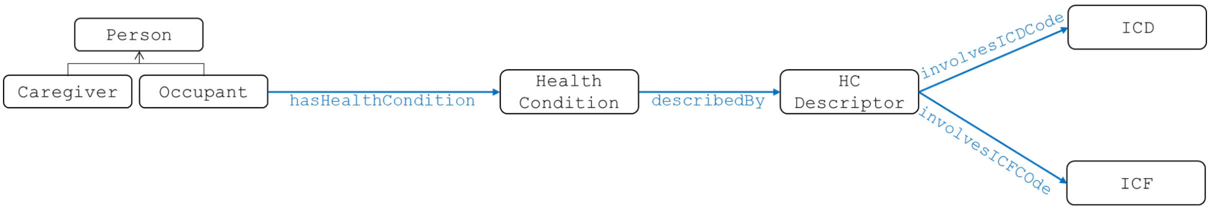

Figure 2: Relations between Occupants, Health conditions, and their Descriptors. Rounded boxes represent classes identified by their labels, black arrows indicate the rdfs:subClassOf relations, and blue arrows indicate object properties.

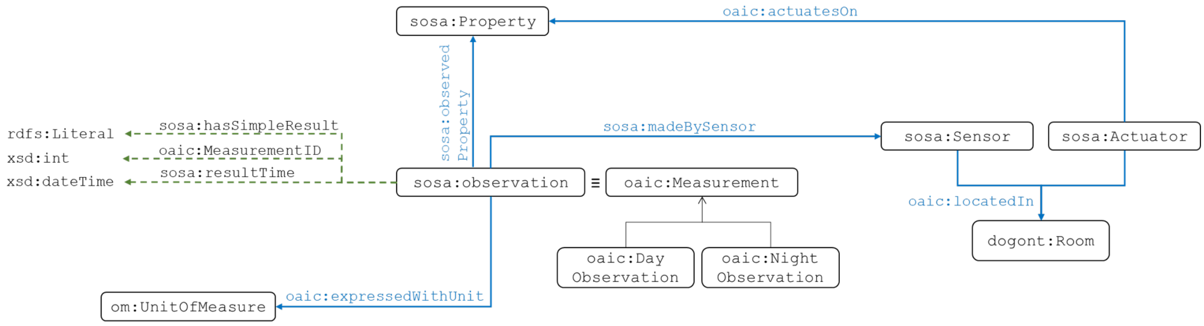

Figure 3: Relations between Observations, Sensors, Actuators, Unit of Measure, and Rooms. Rounded boxes represent classes identified by their labels, black arrows indicate the rdfs:subClassOf relations, green dashed arrows indicate datatype properties, and blue arrows indicate object properties.

representing the impaired functions (with the datatype property `oaic:ICFGenericQualifier` for quantifying the magnitude of the impairment). To assess and quantify the most common mental disorders affecting older adults, OAIC models as datatype properties the results of widely adopted tests:

- **Depression** is quantified using the Geriatric Depression Scale (GDS) – Short Version [55]; this scale may be used to monitor depression over time in all clinical settings. Any score above 5 on the GDS can be considered as a mild depression, while scores between 5 and 8 can be considered moderate depressive disorder, and finally, scores greater than 8 indicate severe depressive disorder.
- **Anxiety** is quantified relying on the Geriatric Anxiety Inventory (GAI) - Short Form, which, for scores greater than or equal to 3, indicates a possible form of anxiety.
- **Sleep disorder** is quantified with the Geriatric Sleep Questionnaire (GSQ) - 6 item version [56], which gives positive results for scores above 15.

4.2.2. Sensors, measurements, and actuators

OAIC reuses many concepts from SOSA, namely `sosa:Sensor`, `sosa:Observation`, which becomes `oaic:Measurement`, and `sosa:Actuator`, together with all the object and datatype properties relevant for the correct functioning of the related patterns. Each sensor performs observations, which are characterized by an ID, a datetime stamp, and a `sosa:hasSimpleResult` property that explicits the measurement value. Each `sosa:Observation` is expressed in a unit of measure (by reusing the Ontology of units of Measure (OM) [57]) and assesses the value of a `sosa:Property`, physical characteristics of interest which, in OAIC case, are the set of comfort metrics measures by sensors (i.e., CO, CO, CO, TVOC, PM2.5, flicker, humidity, illuminance, ventilation, temperature). Similarly, `sosa:Actuators` perform `sosa:Actuation` over (one or more) `sosa:Property`. Both sensors and actuators are located in `dogont:Rooms`, the set of rooms composing a domestic environment - borrowed from a subset of the DogOnt model [58]. Figure 3 depicts the TBox and the relationships occuring among these concepts.

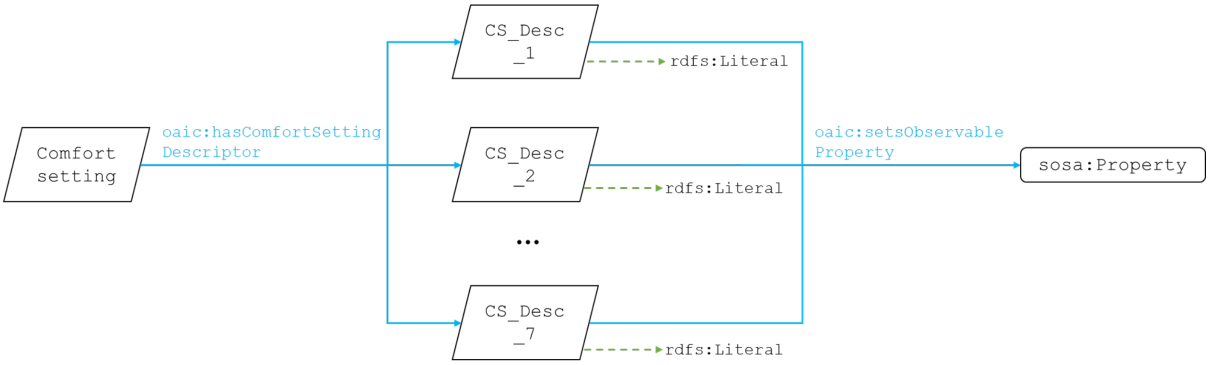

Figure 4: A representation of a Comfort setting individual and the descriptors composing it. Parallelograms represent individuals, rounded boxes represent classes, green dashed arrows indicate datatype properties, and blue arrows indicate object properties.

4.2.3. Comfort setting

Comfort settings are instantiated as individuals of the `oaic:ComfortSetting` class, which is further specialized into the `oaic:GeneralComfortSetting` and `oaic:TailoredComfortSetting` subclasses. This partition answers to experts' request of distinguishing between a *neutral* comfort setting and *tailored* settings that are explicitly developed to support the healing of specific mental conditions. The choice of modelling comfort settings as individuals traces back to previous studies [29, 26], in which the definition of user-centered settings was defined. Therefore, as depicted in Figure 4, each comfort setting `owl:Individual` is characterized by a number of descriptors equal to the `sosa:Property` that needs to be observed; then, each descriptor is completed by a datatype property specifying the value of the involved property. The `oaic:GeneralComfortSetting` individual foresees the definition of seven settings - thus, it involves seven descriptors.

As an example, the following OWL code (serialized in Turtle) represents the definition of maximum and minimum indoor temperatures (for winter and summer seasons) assigned to the `oaic:CSDescr2-1` descriptor for a `oaic:GeneralComfortSetting` individual:

```
oaic:CSDescr2-1 rdf:type owl:NamedIndividual , oaic:
    ComfortSettingDescriptor ;
oaic:setsObservableProperty oaic:Temperature ;
oaic:TempSummerMax "23"^^xsd:int ;
oaic:TempWinterMax "22"^^xsd:int .
```

According to the domain experts, the general comfort setting specifies the following comfort values for seven observable property:

- CO maximum concentration: 800 ppm;
- standard lighting set at 400 lux;
- PM2.5 maximum concentration: 10 µg/m3;
- winter indoor temperature between 20 and 22° C., summer indoor temperature between 23 and 26° C.;
- winter indoor humidity between 20 and 50%, summer indoor humidity between 40 and 60%;
- CO maximum concentration: 300 ppm;
- TVOC (Total Volatile Organic Compounds) maximum concentration: 100 ppb.

4.2.4. Rules

To illustrate the business logic underlying OAIC [59], rules were developed with domain experts. Considering the expressiveness required by the use cases, SWRL was chosen as rule language. The rules serve three purposes:

- Classifying an `oaic:Occupant`'s `oaic:HealthCondition` according to the magnitude of his/her scale value(s): for instance, the rule

  ```
  Occupant(?occ), hasHealthCondition(?occ, ?hc), hasDescriptor(?hc
      , ?hcd), GDSscale(?hcd, ?gds), greaterThanOrEqual(?gds, 9),
      lessThanOrEqual(?gds, 11) -> 6A71.1(?hc)
  ```

  checks for the occupant's Geriatric Depression Scale (attributed by a clinician) and classifies the health condition as belonging to the ICD `icd:6A71.1` (labelled "Recurrent depressive disorder, current episode moderate - without psychotic symptoms").
- Checking whether a `sosa:Observation` individual value falls within the ranges specified by the `oaic:GeneralComfortSetting` (or the `oaic:TailoredComfortSetting` if it is specified).
- In case a values exceeds the threshold(s) represented in the `oaic:GeneralComfortSetting` or `oaic:TailoredComfortSetting`, identify the proper `sosa:Actuator` and activate it (by setting `true` the value of the `oaic:activate` datatype property).

Rules were defined with domain experts during the *Analysis and conceptualization* phase and represent a subset of those cases experts have experienced during their working activities. Considering the prototypical nature of OAIC, the focus of rules was shifted towards older adults and their mental issues, and indoor comfort metrics management, rather than representing actuation in a complete way. In the following Section 4.3, three use cases depicting the role played by SWRL rules are presented.

4.3. Use cases

To conclude the *Development and test* phase foreseen in AgiSCOnt, the prototype ontology was tested against some use cases. Their purpose is to show domain experts and ontologists whether the prototype complies with their expectations and to rectify authoring issues - if acknowledged. The reasoner Pellet [60] was selected due to its ability to treat SWRL built-ins.

4.3.1. Occupant with mild depression

Mr. Arco (82) lives alone in his apartment and suffers from mild depression (`icd:6A71.0`), reporting a GDS score equal to 7. Moreover, he is affected by Chronic Obstructive Pulmonary Disease (COPD) (`icd:CA22`), which limits his freedom of movement and activities. To avoid COPD exacerbation and to mitigate his depression, the air purifier (a `sosa:Actuator`) is activated whenever the following rule is true:

```
Occupant(?occ), hasHealthCondition(?occ, ?hc), (6A71.0 or 6A71.1 or
    6A71.3 or 6B00 or 6B01 or 6B04)(?hc), locatedIn(?occ, ?room),
    Observation(?obs), madeBySensor(?obs, ?s), locatedIn(?s, ?room),
    observedProperty(?obs, ?pro), hasSimpleResult(?obs, ?v),
    definedComfortSettings(?occ, ?cs), hasComfortSettingDescriptor(?
    cs, ?csd), CO2max(?csd, ?vmax), greaterThanOrEqual(?v, ?vmax),
    CO2Actuator(?a), locatedIn(?a, ?room), actuateOn(?a, ?pro) ->
    activate(?a, true)
```

This simple rule allows Mr. Arco to avoid his respiratory conditions and the exacerbation of his mental disorder. This rule works together with similar rules setting the minimum lighting foreseen by the `oaic:GeneralComfortSetting`, as well as other rules monitoring air quality.

4.3.2. Occupant with sleep disorders

Mrs. Rossi (76) lives on her own after her husband's departure. She suffers from chronic insomnia (`icd:7A00`) and other diagnosed sleep function disorders (`icd:VV01`). Her physicians recommended an indoor temperature around 20° C. during sleep time and the adoption of blackout shutters to limit exposure to light during the night. Her daughter sets up a `TailoredComfortSetting` to implement these changes in Mrs. Rossi's bedroom. Therefore, the following rules are enforced:

```
Occupant(?occ), hasHealthCondition(?occ, ?hc), (VV01 or 7A00 or 7A60
    or 7A61 or 7A62)(?hc), isTakenCareBy(?occ, ?care),
   setsTailoredComfortSetting(?care, ?tcs),
   hasComfortSettingDescriptor(?tcs, ?csd), NightObservation(?obs),
   madeBySensor(?obs, ?s), locatedIn(?s, ?room), Bedroom(?room),
   observedProperty(?obs, ?pro), hasSimpleResult(?obs, ?v),
   nightTemperature(?csd, ?settemp), notEqual(?v, ?settemp),
   TemperatureActuator(?a), locatedIn(?a, ?room), actuateOn(?a, ?pro
   ) -> activate(?a, true)
```

and

```
Occupant(?occ), hasHealthCondition(?occ, ?hc), (VV01 or 7A00 or 7
   A60 or 7A61 or 7A62)(?hc), isTakenCareBy(?occ, ?care),
   setsTailoredComfortSetting(?care, ?tcs),
   hasComfortSettingDescriptor(?tcs, ?csd), nightIlluminance(?csd,
   ?nv), NightObservation(?obs), madeBySensor(?obs, ?s), locatedIn
   (?s, ?room), Bedroom(?room), observedProperty(?obs, ?pro),
   hasSimpleResult(?obs, ?v), notEqual(?v, ?nv), Shutter(?a),
   locatedIn(?a, ?room), actuateOn(?a, ?pro) -> activate(?a, true)
```

The two rules exploit the equivalence `sosa:Observation` `oaic:Measurement`, which enables the generation of two subclasses of measurement (`oaic:NightObservation` and `oaci:DayObservation`) which depend on the specific `sosa:resultTime` value attached to each observation. In this way, the caregiver can set the night (and day) duration, and the actuators will activate only if the indoor measurements are performed at a specific time of the day.

5. Limitations and Future research directions

The work on OAIC is still in its early stages, and several limitations remain to be addressed. First, considering the prototypical characteristic of the ontology, the focus on older adults' mental health is mostly on single disorders; however, as highlighted in Section 3, older adults may face more than one mental disorder at the same time. In the next stages, domain experts will be involved in how to tackle multiple mental conditions and comorbidities, identifying priorities to avoid conflictual comfort settings. Among the mental issues not explicitly addressed in this work, solitude also needs further investigation; to this end, two research directions can be followed: 1) recurring to domain experts' knowledge and model solitude as if it was a mental health concern, and b) including OAIC in a broader AAL framework which can foster digital socialization (e.g., as in [61]). From an ontology perspective, the representation of the actuation is currently simplistic. This is partly due to the necessity of focusing on older adults' mental health, and partly to the need to identify a) a set of actuators that can be controlled remotely and b) other relevant ontologies that can be used in this field. So far, the OAIC ontology has completed the first two phases of AgiSCOnt's methodology (i.e., *Analysis and conceptualization* and *Development and testing*): with the interaction with other domain experts and the collection of further requirements, the ontology can change considerably in some aspects. It is also relevant to underline that, so far, OAIC deals with single occupants (older adults living alone or living in a nursing home in which they have their own room). This limitation must be assessed to identify the possibility of having OACI manage different conditions for multiple occupants (characterized by different health conditions). Nevertheless, it is also fundamental to gather consensus on the model and its scope. To this end, OAIC needs to be disseminated to other relevant stakeholders and an evaluation of its inferences and their values for the stakeholder community must be performed (as it happened for other health-related and ontology-based projects [62, 63]). This is part of a comprehensive, evidence-based validation strategy informed by practices in architecture, gerontology, and psychology [64]. Semi-structured interviews conducted with stakeholders have the opportunity to explore the emotional and content relevance of system constructs and collect qualitative suggestions for enhancement.

6. Conclusions

This work presents OAIC, an ontology-based system aimed at supporting the mental health of older adults by managing indoor comfort conditions. Unlike traditional AAL solutions, OAIC uniquely emphasizes the correlation between environmental metrics and mental well-being, offering tailored comfort interventions through semantic modelling and automated actuation. Developed collaboratively with clinical and technical experts, OAIC integrates standardized health classifications and sensor data to infer actionable insights, thereby enabling personalized, health-supportive environments. Initial use cases demonstrate the feasibility of addressing specific mental health conditions, such as depression and sleep disorders, through indoor environment control. While still in development, OAIC provides a foundation for future systems that promote psychological well-being and independent living among the elderly. Future work will focus on validation, refinement, and stakeholder evaluation to ensure the clinical relevance, usability, and integration of the ontological model into broader AAL ecosystems.

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Declaration on Generative AI

The author(s) have not employed any Generative AI tools.

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