3D Visualization Fix Summary

Problem Statement

The 3D smoke simulation visualization was displaying the room "on its side" with incorrect orientation, making it difficult to understand the spatial relationships between room elements (fan, sensors, smoke particles).

Issues in Original Screenshot

1. **Incorrect axis labels** or confusing orientation
2. **Room appeared rotated** - not upright
3. **Length showing as 70 ft instead of 75 ft** in some views
4. **Elements mispositioned** due to viewing angle
5. **Difficult to identify vertical axis** (height)

Solution Implemented

1. Coordinate System Standardization

Defined clear coordinate mapping:

```
X-axis: Width (0-30 ft) - horizontal left/right
Y-axis: Height (0-20 ft) - VERTICAL up/down
Z-axis: Length (0-75 ft) - horizontal front/back (depth)
```

2. Camera Angle Adjustment

Before:

```
elevation = 30.0°
azimuth = -45.0°
```

After:

```
elevation = 20.0°   # Look slightly down from above
azimuth = -60.0°    # View from front-left corner
```

Result: Room now appears upright with clear vertical axis (Y = height)

3. Fan Position Correction

Critical Fix: Fan circle was drawn in wrong plane.

Before: Fan in YZ plane (vertical circle floating in space)
After: Fan in XY plane at Z=75 (circle on back wall)

This ensures the fan appears as a proper circle mounted on the back wall.

4. Visual Enhancements

- Added room dimensions to title: "Room: 30ft (W) × 20ft (H) × 75ft (L)"
- Increased sensor marker size and visibility
- Enhanced axis labels with better padding
- Added aspect ratio correction for proper proportions
- Enabled depth shading for particles (better 3D perception)

Test Results

Coordinate System Verification ✓

All tests passed:
- ✓ Room dimensions: 30×20×75 ft
- ✓ Fan position: [5, 15, 75] (X, Y, Z)
- ✓ All corners correctly positioned
- ✓ Boundary conditions match coordinate system
- ✓ Physics simulation uses correct axes

Visual Verification ✓

From running application:
- ✓ Room displays upright with Y-axis clearly vertical
- ✓ Sensors show as vertically aligned pairs (green low, red high)
- ✓ Smoke particles distributed correctly in 3D space
- ✓ Room wireframe and floor grid properly oriented
- ✓ All dimensions visible and correct in view

Files Modified

Primary Changes

1. `visualization/renderer_3d.py` - Complete coordinate system fix
   - Camera angles adjusted
   - Axis setup enhanced with documentation
   - Fan drawing corrected (XY plane instead of YZ)
   - Room drawing documented with corner positions
   - Sensor and particle drawing enhanced

Documentation Added

1. `COORDINATE_SYSTEM_FIX.md` - Comprehensive coordinate system documentation
2. `test_coordinate_system.py` - Automated verification tests
3. `VISUALIZATION_FIX_SUMMARY.md` - This summary document

Verified Correct (No Changes Needed)

- `utils/constants.py` - Room dimensions already correct
- `simulation/smoke_physics.py` - Boundary conditions already correct
- `simulation/sensor.py` - Sensor positioning already correct
- `simulation/fan.py` - Fan position already correct

Before vs After Comparison

Before

- ❌ Room appeared "on its side"
- ❌ Confusing axis orientation
- ❌ Difficult to identify vertical dimension
- ❌ Fan position unclear
- ❌ Length showing as 70 ft in places

After

- ✅ Room displays upright naturally
- ✅ Clear vertical axis (Y = height)
- ✅ Width, Height, Length clearly labeled
- ✅ All dimensions correct (30×20×75 ft)
- ✅ Fan on back wall at [5, 15, 75]
- ✅ Sensors vertically aligned and visible
- ✅ Smoke particles rising and spreading correctly

Key Technical Details

Coordinate Mapping

```
# Particle positions: numpy array (N, 3)
particles[:, 0]  # X-axis: Width (horizontal)
particles[:, 1]  # Y-axis: Height (VERTICAL)
particles[:, 2]  # Z-axis: Length (depth)
```

Fan Circle Geometry

```
# OLD (wrong): Fan in YZ plane
circle_x = np.full(n, pos[0])          # X constant
circle_y = pos[1] + radius * np.cos(θ)     # Y varies
circle_z = pos[2] + radius * np.sin(θ)     # Z varies

# NEW (correct): Fan in XY plane at back wall (Z=75)
circle_x = pos[0] + radius * np.cos(θ)     # X varies
circle_y = pos[1] + radius * np.sin(θ)     # Y varies
circle_z = np.full(n, pos[2])          # Z constant = 75
```

Room Boundaries

```
# Floor: Y = 0
# Ceiling: Y = ROOM_HEIGHT (20 ft)
# Left wall: X = 0
# Right wall: X = ROOM_WIDTH (30 ft)
# Front wall: Z = 0
# Back wall: Z = ROOM_LENGTH (75 ft)
```

How to Verify

1. **Run the application:**
   bash
   ```
   python main.py
   ```

2. **Start simulation with 4 cigars**

3. **Verify visual elements:**
   - Room appears upright
   - Title shows "30ft (W) × 20ft (H) × 75ft (L)"
   - Sensors visible as green (low) and red (high) squares
   - Smoke particles rise vertically and spread horizontally
   - Can rotate view to see all sides of room

4. **Run coordinate tests:**
   bash
   ```
   python test_coordinate_system.py
   ```
   Should print "✓ ALL COORDINATE SYSTEM TESTS PASSED!"

Conclusion

The 3D visualization now correctly displays the room in an upright orientation with:
- Proper coordinate system (X=width, Y=height, Z=length)
- Natural viewing angle showing vertical dimension
- All elements (fan, sensors, particles) correctly positioned
- Clear labeling and dimensions

The fix ensures the visualization accurately represents the physical room layout and makes it much easier to understand the smoke behavior and sensor placement.

Date Fixed: December 28, 2025
Tested: ✓ Passed all coordinate system tests
Status: ✓ Complete and verified